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PERSONNEL RELATIONSHIPS IN INDUSTRY.*

BY

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Those who live and work in Philadelphia are fortunate. We make up here a population of earnest and honest people.

The public, parochial and private schools are good. The evening schools offer excellent classical courses, and the technical schools, both day and evening, give elementary instruction to those who look for elementary education and carry the more ambitious ones as high as they desire.

The Franklin Institute offers very unusual opportunities for advanced study under renowned teachers.

Long experience in manufacturing in this city has taught me that there is a great population here made up of men who desire to earn a living and to spend their earnings in the care of their families.

The thoughts that are expressed in this article are not universally applicable. Different populations, different nationalities, different classes of work and different business conditions affect profoundly the relations between employer and employee.

Over a period of many years we have developed in our works certain principles and methods which have been emi-

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nently satisfactory to us and to our employees. In what follows I shall try to outline these principles and methods.

We do not profess to know all about the subject. The opinions expressed may appear erroneous and perhaps very often are erroneous. They nevertheless are the opinions we have been led to by careful study of the problem. If the expression of my views should stimulate discussion of this very important subject, then perhaps this effort will have been justified.

Some managers have what they call a "policy" in their dealings with their customers, their sources of supply and their employees. This word "policy" is often used as the Oriental uses the term "face," and sometimes involves in its meaning pretense. It is something that is supposed to resemble what the card player would call "poker face." Playing a game with the purpose of getting the advantage of the one with whom you are playing.

Whether this practice is justifiable in dealing with one's customers and one's sources of supply is questionable. As regards the relations between employer and employee, such an attitude of mind is thoroughly inexcusable and out of place. The first approach to what might be called an "employee policy" requires the entire elimination of the question of "face."

The relationship is essentially a personal one, even though authority be necessarily delegated by the employer, and if mutual respect exists, differences of view and of temperament may be sympathetically dealt with on both sides and eventually solved.

Our family relationships are cemented by many ties of affection and respect.

Relations between friends are tied by congeniality of temperament or mutuality of interests.

In the small businesses of an earlier day we read that what would be called factory relations partook to some extent of the character of family relations, and there is a charm in the thought that employer and employee sat down to the table together. One may suspect that this was not always so pleasant as it is said to have been, and perhaps the very intimacy of the association sometimes built up recrimination.

Obviously, in the larger business establishments of today, the family aspect of the business group has long since disappeared.

There was a period in which men of the same occupation were gathered in guilds, lived in the same quarter of the city, and made a class of themselves. There is no evidence that there is any inclination on the part of the average citizen to revive this old custom. When a man shuts down his loom, or his lathe, or closes the lid of his desk, he desires to go to his family and friends, and not to spend his time with his shopmates.

The employer may be an individual. He is more likely to be a corporation. The corporation head may be the founder of the business with a personal pride in the business, and to him the business is more than life. Or the head of the corporation may be a salaried man, appointed by stockholders, with but a small investment in the business.

In any of these cases there is a mutuality of interest between employee and employer, and there should be a mutual desire to produce good goods at low price and to serve the customer well. Otherwise neither will prosper.

These relationships are today the subject of much discussion. There are many contacts, daily and hourly. Many troubles on each side. The employee needs more money, has sickness at home, has children he wants to properly prepare for life. The employer has harassments unbounded. If the employer is considered successful and has plenty of business on which he presumably is making money, there is no reason to think that he has had an easy time. The only correct assumption is that he has applied himself so intensely as to accomplish what the less prosperous business has failed to accomplish.

The major relationship between employer and employee lies in the division of the income from the business. There are many other relationships which would be called minor, but which often are the most difficult to adjust. The little annoyances or hitches which develop day by day. The distress which comes to an employer or one of his staff because of some negligence or some incompetence in any employee. The distress which comes to the employee from minor an-

noyances which crop up day by day, and which at the moment are more momentous than the major relationship.

Very early in our business, Dr. E. H. McIlvain was made responsible for our personnel relations. The reasons for his selection were: his wide experience as a workingman in various countries and in different classes of business; the knowledge of life that came from his practice as a physician; his ability to judge character and temperament as a result of his training as a physician; his ability to understand the physical and mental attainments of employees and to place them in positions where their abilities would serve the company and the individual best; coupled with this his ability to avoid placing a man in a position where he is what we call a "misfit" and where his spirit would be broken.

These were all valuable characteristics. He had others A very high sense of justice, sound judgment and unlimited courage.

There are angles of the personnel relations which can only be satisfactorily understood by those who know very thoroughly the human body and its mechanics, and those characteristics which are related to a man's nervous complexes and his mental complexes. Some of it borders on psychology and the spiritual values.

The subject is a profound one. It intermingles with business necessities and uncertainties. I do not believe it can be successfully dealt with without the joint endeavors of those who take into consideration the human body, the business problem and the spiritual problem.

It has to do with almost the entire relationship between humans.

It has to do with public health, family relationships and the relations of the individual to government.

It serves the sum of human happiness and justice.

It involves the proper adaptation of a citizen's physical and mental qualities to his means of earning a livelihood.

I have found that the cultured physician has many of the qualifications necessary for understanding the subject.

Quite often this reseach has started from the charitable standpoint, under the guidance of well disposed people who

are often ignorant of the necessities of the business and of the people they are studying.

My strong impression is that the studies should start from the other end, that a physician, by the study of a man's physique—mind, bones, flesh, spirit—knows best how to utilize the employee's efforts in directions in which he can be successful, to see that his work is so congenial to his body and mind that the effort in itself will strengthen his body and mind.

The psychologist, or the reformer, is apt to form judgment and lay down courses based on his desires rather than his knowledge of the capacities of the man he is analyzing.

The physician will have an equal goodwill, but his decision will be the result of his observation of the human being, much as an engineer would determine the capacity of a machine by his knowledge of the parts of the machine.

It involves the study of man en-masse and man individually.

This study has been neglected. Our law business and our engineering are in the hands of highly trained technicians. Our personnel business has been to too great an extent in the hands of people who are not trained, and their actions have too often been the result of impulse or business emergency.

A great new profession can be developed here with untold benefits. I venture to suggest that one foundation of this class of work should be the medical profession, and that many doctors could find their best field of endeavor in the personnel establishments of industry.

SELECTION OF EMPLOYEES.

The employee is first selected by the employment man, and his decision is based on the experience of the applicant and his general appearance. He is then sent for medical examination and the medical examiner must know the work to which the man is assigned. A physical defect should not in itself be a ground for rejection, but it might be that the physical defect would make the man unsatisfactory for that particular position.

Certainly a blind man cannot act as a guide for visitors, a nervous man would not make a good press operator, but there might well be many jobs in the shop which a blind man would

fill to advantage and which a nervous man could fill to advantage.

The medical examiner is a better judge of such matters than the employment man can possibly be, and he must be alert to revise the decision of the employment man, find some job suitable for this particular man, and tell the employment man that he must send in another candidate for this particular position.

The medical examiner may be a highly trained and skillful physician, but this does not fill all the requirements of his position. He should examine a man in a room with no others present. He has certain questions he must ask the man. He must know the man's age, nationality, in what section of the city he lives, whether he is married, has children, where he worked last, what other places he has worked. A well educated and observant person will learn much in asking these questions and be able to judge something of the applicant's adaptability and his desirability as an employee and shopmate.

The doctor should take plenty of time for the examination, no matter how many there may be awaiting examination. As he asks the questions he observes the man's manner, tone of voice, mental reactions. After careful weighing of the information elicited by the foregoing questions, the doctor has largely satisfied himself as to the man's character and physical makeup. He looks at the man's tongue and this inspection is revealing to the medical man. He listens to his heart and makes note of it. He observes the condition of the man's chest. By a little readjustment of the man's clothing, and no unnecessary exposure, he examines the man's abdominal wall, and tests him for hernia. He tests the man's hearing. He has the man take a posture and stand with his eyes closed. This reveals some things to the physician.

The examination indicates to the physician some measure of the man's home life and habits. The man stands on the scale to be weighed. All this gives opportunity for a little conversation with the applicant, and at the end of the examination the medical examiner should know a great deal more about the wisdom of employing the man, and the nature of the work for which the man is fitted.

It is rarely necessary to strip the man. If the doctor has some suspicion as to the condition of the man's chest or heart, opening a few buttons of his shirt gives sufficient excess. If the doctor has the proper personality this examination will be an interesting experience for the candidate rather than an offensive one.

A man with a rupture is a perfectly good employee if placed at suitable work.

A man who comes to us with a bad heart can be placed where his heart will be strengthened.

A man with arrested consumption can be regenerated in a factory.

There are places in our factory for a blind man, a deaf man, a man with one arm and a man with one leg, but the employment of a man with any of these defects puts an added responsibility on the medical department. The arrested consumptive has to be guided somewhat in his home life and in his food, and if one takes the responsibility of giving employment to such a man, it is necessary that the man's progress be continuously observed, with the expectation on the part of the Personnel Department that he will be rehabilitated and under no circumstances broken down.

A supersensitive employee might say that rehabilitation is no affair of the Budd Company, but all must agree that we are responsible for putting a man where he will not be wrecked.

A man who has a defect will as a rule make an unusually good employee, because he appreciates having the position and because no doubt he has frequently been rejected elsewhere. The very fact that he has a position which pays regular wages will often be the best possible tonic to rebuild the man's injured nerves or tissues. There is a gardener in Philadelphia who is both deaf and dumb. He is a most faithful and skillful workman.

It is the aim of our company to have so far as possible only people of good character on its payroll, but after eliminating the vicious characters, it should be our aim to have a complete cross section of the community as regards age and physical characteristics, and this need be no economic burden to the company. We believe there is enough of good character

in all of our employees to assure a welcome on the part of the physically sound to those who are less sound. We need in every large industry the strong man, the nimble man and the brainy man. So far as possible we need a sense of confidence in every employee that work will be continuous and that he won't be subject to arbitrary dismissal.

AGE.

An arbitrary ruling that people should not be employed earlier than a certain age or later than a certain age is entirely unwise.

If we think only of the usefulness within the shop, middle age in many cases is the most desirable. There is more likelihood of being regularly at work, the man no doubt has gathered some experience in living with shopmates, and if he has had the habit of change, perhaps it has been sufficiently indulged and he is glad to stay permanently with us. We must realize that the age of retirement is nearer and the man who comes with us in middle life will perhaps be a responsibility of the company before many years. This has become a more serious matter in recent years because of the laws in regard to sickness and retirement compensation.

One cannot dispute the assets of youth. If a young man has sufficient ambition and mental and physical characteristics to pass our Personnel Department, then we know he will have the verve to attack his shop duties with ambition and will have the adaptability of youth. He will be willing to serve in order that he may learn to lead. He will learn the business and may grow to fill leading positions in the organization. Young men entering our employ will become active and skillful workmen, and will take part in what might be called the social life of the factory.

A number will drift away and the money the company may have invested in them will be lost. The factory with too large a per cent. of youthful men will not have the stability that it should have, and a factory with too large a per cent. of older men will not have the virility.

The management must bear in mind that the young men year by year are growing older, and perhaps the advance in age of these young men will supply all the older men the

company should have. If a man has been with the company for years, he is bound to reach the time in life where the duties he can perform to advantage are limited. It is better that the leading positions should be attained by those of our own people who are advancing in years rather than by men who have given their best endeavors to some other company.

For the above reasons fixing an age for employement can only hurt the interests of the company. The selecting of men as regards age is one of the most delicate and important duties that the Employment Department has, and its policy must be guided by the best, broadest and most thoughtful consideration on the part of the head of this department.

SHOP REPRESENTATIVES.

That tradesmen should unite into trade organizations is natural and is the business of none but themselves. Almost every one belongs to a lodge, a church, beneficial association or a trade union. These are matters that cannot in any way concern an employer. If some of our men belonged to a group of banditti it would still be none of the business of their employer, unless it might make conditions in the shop disagreeable to their fellow workmen or endangered the company property, in which case it would be the duty of the company to eliminate such.

The right to bargain between man and employer has always existed. No law can add to or detract from this right. Every employee will always be listened to by any official of the Budd Companies, from gang boss to president, and will be talked to as man to man. Any group of employees will be listened to.

In recent years great dependence has been placed on organizations, elections and representatives, and in our plant in Philadelphia we have had for some years a representation system which appears to make a contribution to the operation of the plant.

When we have a request from an individual, the granting of this request may interfere with the wishes or the privileges of some other individual, and it is possible that the company's and the employee's best interests are served by carefully se-

lected representatives who can consult with the proper officials.

In order, however, to attain the proper community of interest between each individual and the company, we believe any individual must have access to any official. It must be the very great responsibility of every executive, large or small, to always have an ear open to requests or comments on the part of any employee. The employee must understand that he has the right to state his case, and that it will receive careful consideration. He must, however, realize that his point of view cannot always be followed. In such a case, whether the situation is going to result in a feeling of discontent and dissatisfaction on the part of the employee depends a great deal on the spirit and attitude of the company representative. Our motto has always been as stated by the Scotch poet—"A mon's a mon for a' that." This may be stated as follows:

There are many of us within the walls of the factory with a variety of talents. Our compensation will greatly vary, but there is one characteristic in which we are all alike and all equal. That is in our personal manhood, and the respect that each one must have for the personality of every other man.

In Detroit there has been a tremendous amount of agitation by labor organizers and much costly strife. Practically all the employees of all the factories resigned their right to deal with their employers and insisted that those dealings pass through outside managers, or labor leaders. After this had swept all over the city, we found that a majority of our employees thought this way, and so our company in Detroit had to give up dealing directly with its employees, and at their request dealt with the outsiders. This was their wish, and as men they have the right to make such a decision. Just as far as possible we continue to give the person employed the full right to negotiate personally in addition to such rights as he has assigned to the outsider.

There are many powerful people in the world and many powerful and threatening groups of people, but there is nobody powerful enough to make the Budd Company quarrel with its own employees. That we will not do.

I trust that in the remaining years of my lifetime we can continue to deal with one another as in the past.

This whole subject has many heartaches in it. Many men have been led to attack the business upon which they depended for employment because of fear of physical violence from mobs. What can the employer do? Needless to say, much of the solution lies with the individual himself. Many labor leaders are so desparate and depend so much on terrorizing the workingmen that we cannot underestimate the seriousness of the workingman's reflections when he has to decide which side to take. In anything like normal times, such violence would be prevented by those who are responsible for the law and order of the city. If it were known that the Mayor of a city wanted to prevent people from being hit with brickbats or blackjacks, then the police would be quick enough to do their duty, and under these circumstances the outlaws would stay out of the city and there would be no disorder. Violent conditions can only exist under bad city government. The first interest of us all is to see that we have a government in the city which will prevent one man from attacking another.

Our company can see to it that it has an ample force of able, well trained, well equipped and discreet watchmen so as to give full protection within and at the gates of the plant. It is our belief that the wave of disorder which swept over the country has spent its force and won't recur in the near future. If so, the people of Philadelphia and we in the Budd plant have much to be thankful for.

NURSES.

As with the doctor, so with the nurse, more is needed than technical training and experience. The nurses should be divided into two groups, one for work within the factory, the other for work outside.

When seven thousand people are gathered in an institution for eight hours a day, there are endless needs for a nurse's service. Everything from bleeding noses to serious sickness will happen over and over again all day long. In the old days there was a man in the shop who could take dirt out of his shopmates' eyes, and another could tie a dirty rag around a cut finger. We have learned some things since then, and it is desirable that even the slight injuries should be properly attended to by a skillful nurse.

A record has to be kept of the man, the nature and extent of the injury. There are some minutes of personal contact between the nurse and the man. The man comes to know the nurse and the nurse comes to know the man. This results in good. After the treatment it is presumed that the man will think—"Well, she's a skillful body and she took good care of me." The nurse on her side should feel that the man is a manly fellow and of the kind we should have in our shop. The redressing gives other contacts. The surroundings are not strange to the man. This is where he was employed. In this office is the man who made his physical examination. He may see the clerk who entered the data for his employment. We recently had an employee who had broken his arm in some athletic contest. He had to come for redressing day after day, and he was so pleased by the consideration shown to him by the nurse that he remarked it was almost worth having a broken arm.

Years ago many workmen became crippled from what was called rheumatism as they came a little past middle age. This was partly because working conditions were harder, living conditions were worse, and the average man was fed and clothed less well, but a good deal of it was due to the continuously, day after day, carrying on more or less similar operations. The result often was that the man became a complete cripple before he was sixty. This can be almost entirely avoided nowadays by proper observation of employees, plus an examination to show if there is any source of infection. The use of electric current and of various heating appliances, and simple rubbing and exercising of the affected spots will correct the trouble and greatly extend the man's period of usefulness and ease his later years.

There should be such an atmosphere in the shop that the employees will seek the treatment, and such an observation of the physical condition of all employees that the medical department will detect defects even if the employee does not ask for assistance. This again brings intimate contact between the employee, the medical department and the nurse, all of which has beneficial effects beyond those which are medical.

The contact which the inside nurse has in treating the little injuries, and the contact which the outside nurse has in the calls at the homes of employees, must be concisely reported so that the heads of the personnel department can have complete records to guide them in dealing with the employee.

We all know that if we had only a hundred men in our factory and one of them had a death in the family, the heads of the company would be concerned in regard to their shopmate's misfortune. The situation becomes more difficult with great numbers, but if we are justified in employing great numbers, then we must accept the obligation that goes with such employment.

The outside nurse should be provided with an automobile, and at times it is desirable that she have a chauffeur. A man who is absent is supposed to send word on postal cards which are prepared for his use, indicating the reason for his absence and when he expects to be back. If there is sickness the nurse calls at the house. Probably it is not the man himself who is ill but someone of the family. There may only be need for the courteous inquiry which would be welcomed by any of us under similar circumstances, or the nurse may find need for something more. Certainly the management would be something less than human if it were not concerned by the illness or death of one of its employees or in the family of one of its employees.

For this kind of work special talents are required. The nurse must be a good judge of human character. She can by her actions either be a welcomed visitor and in some cases an angel of mercy, or by her inept conduct offend the family. Very exceptional qualifications are required, but there are many wise and capable women in the nursing profession, and women of the proper character can be obtained.

A factory is a place to produce useful goods at a profit to both employees and to the business. It cannot afford to do what a hospital does, and high-minded employees would be offended if the factory did go beyond certain limits.

It must also be borne in mind that the purpose of a factory is to produce good goods at low cost. We have an accounting department to enable us to effectively conduct the operations of the company. We have a laboratory to enable us to

properly prepare materials and treat them properly when they are being manufactured. Each of these departments is productive of profits to the company. The personnel department is another department a thoughtless man might consider a financial burden, but properly conducted, the personnel department can be, and should be, one of the most profitable of all the departments, even though it involves a very considerable financial outlay.

ACCIDENTS.

Last year out of our six thousand employees, two were killed while at work.

In one case a young man playfully tried to operate a truck and ran it into a hatchway. He was not a truck operator and was not supposed to operate the truck, and we no doubt could claim that he was disobeying orders in so doing.

The other man was struck on the head by a piece of flying timber.

In examining our conscience in the face of this record, we can point out that three of our men were killed by accidents in their own homes, two of them by falling downstairs, and one by asphyxiation, but what management should aim at is not easing its conscience, but utmost safety.

The running of a factory involves the gathering of a large number under one roof, the operation in some cases of complicated machinery, the hauling into the shop of hundreds of tons of steel per day, the rehandling of this material a number of times during the day, and loading this amount into freight cars every day. It involves the use of electricity, gas, high temperature furnaces, acids, the operation of powerful slow-moving presses, and the light fast-moving presses, the constant operation of elevators and conveyors.

The beginning of accident prevention is when the employee is hired. It is to the public interest that a complete cross section of the population of the community be represented in the shop, barring the vicious element. If a man has good character, whether he is big or little, old or young, quick-witted or slow-witted, good eyes or poor eyes, good ears or poor ears, good lungs or poor lungs, good heart or bad heart, we believe he should find a place in our ranks, regardless of whether he is German, Irish, Slav, Polish, English, Russian, Jew or Gentile.

The great responsibility of placing all of these different types where they can safely work lies first with the employment man and secondly with the examining physician. Experience shows that placing the man in the right position not only avoids accidents, but results in cheaper manufacture to the company, better earnings to the individual. I have known one case where a man was misplaced and died in a few hours after starting work. The same man could have been placed where his work, instead of being unfavorable to his health, would have been favorable, and improved him physically, mentally and spiritually.

Misjudgment in placing individuals is rarely fatal to the individual, but is always injurious to the individual and to the company. Certain physical and mental characteristics are required for men operating big and powerful presses. A different temperament is required for those men who work small and rapid presses. A still different characteristic for the man who has to do assembly work. A crane operator requires one type of physical and nerve makeup, and a pusher of trucks another type.

These characteristics often follow along national lines. Broadly speaking, a Slav is suitable for one job and a German for another. The Scotch, Irish, English, all have characteristics which adapt them to certain types of work. We could fairly say that an Italian should not be made a crane operator, and there are other positions in the shop which an Italian fits better than would a Scotchman.

There are some positions where an adventurous spirit is an asset. There are some others where the safe and sure man is essential.

SENIORITY.

Generally speaking, seniority will take care of itself. The man who has been with the company a long time will have a hold on his position which will assure his continuation.

The troublesome part of the problem begins when a man shows a lessening of vigor so that it becomes necessary to find some less active employment for him. When times are good this can readily be done. When times are bad, as in the last few years, it is extremely difficult, and the personnel manage-

ment may even have to discontinue the services of someone whom everyone would like to retain.

An arbitrary ruling that when the force is increased one shall take back the men in the order of their release is entirely unsound and unjust. When there has been a lessening of the force and the time comes to build up the force, the employment department has the opportunity and the obligation to reward the more useful men and those with superior character by early employment. To do otherwise would not only be wasting the money of the company, but it would be unjust to those who have earned better treatment.

Men do differ in their desserts. They are not slaves. They are men. Don't ever permit your judgment to break men down into equals. Keep the best at his best and so far as possible build the rest up to that standard. Keep in mind that after having eliminated the vicious, the remainder have merits of varying degrees. They may have also demerits of varying degrees. Angry denunciation was much indulged in by managers a few years ago. Errors must be noticed, seldom with denunciation, but always with a purpose to alleviate and correct.

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ANNUAL VACATION.

For many years it has been understood that those who are paid by the week and are not paid extra when they work beyond the usual factory hours, should have a vacation with pay, and conversely the rule has prevailed that those paid by the hour, are paid for every hour they work, and are paid extra when they work more than normal hours, and should therefore not receive vacation with pay.

This rule has always seemed logical. Sometimes an entirely logical line of reasoning can be substituted by another line of reasoning which is equally logical. Most employees, prodded by their desire to provide as well as possible for their families, are not willing to lose a week's pay and therefore they do not take a week's vacation. This is a decision they make and it is their privilege to decide. On the other hand, the employer knows it is desirable that the man should take a vacation, and that while the man may have been paid for every hour extra he has worked, still if he worked with energy

and effectiveness for a year for the company, it may be considered that the payment of an extra week over and above the bond would be for the best interests of both. Hence our adoption of the vacation for hourly employees.

For years back it has been difficult for businesses to make any profits, and it might be argued that under these conditions the interests of the business should be considered and the substantial extra money, which amounts to two per cent. addition to the payroll throughout the year, should not be spent. In the opinion of some of us this expenditure will not reduce the earnings of the company, because while the amount of money is substantial, it is probably more than repaid by the improvement in the effectiveness of the employee.

There has come up in recent years another employment problem which has a bearing on this vacation problem. The abrupt shutting down of parts of the plant due to lack of orders is most discouraging and demoralizing to the employees. A man hears Tuesday night that he is not needed Wednesday morning, consequently his pay envelope will be short Friday. Even though the employer may be helpless, the appearance to the man must be one of lack of consideration on the part of the employer. Under the vacation rule, the man has built up to his credit a period of time for which he is to be paid without working, and this can be applied to the employee's wages in the case of these sudden shutdowns. In effect, it is much as though the employer were to give the man some days notice that his services are not needed. This is a consideration on our part which is well deserved by the employee.

PAY ENVELOPES.

There should be no uncertainty in a man's mind as to how much pay is due him. However the pay is calculated, whether by the hour or piecework, the man should know to the penny how much is coming to him. Any slipup on the part of the payroll department resulting in deferring payment, or paying a lesser amount, even though it may be corrected later, is extremely mischievous to the interests of the company.

An employee in some cases has a feeling that he is at a disadvantage in dealing with a firm, and the firm should be so particular about all of its financial dealings that such doubts

as a man may have will gradually be dissipated and he become entirely trustful of his employer.

A man takes his envelope unopened to his wife, and she is the financier for the family. We try to employ high grade people, and high grade people have high grade wives. The distribution of the income is usually carried on with extreme care. Almost the entire amount goes to make up rent and food bills, and after the wife lays this sum of money aside, there is in some cases a comparatively small sum remaining, and her attention is given mainly to this small remainder. If by some oversight a payroll clerk has not included a day's work which the man did, or an hour's work which he did, the wife finds that this remainder, on which her mind is mostly set, is lessened by a considerable amount from what she had expected. It may mean only so small an amount as would buy a pair of rubbers for the child, or may be only a ticket to the moving pictures or an extra vegetable for the Sunday dinner, but it has an effect on her mind entirely out of proportion to the amount of money involved.

How is the interest of a big manufacturing company adversely affected by such a small incident? The housewife cannot reach the paymaster, the superintendent or the proprietor. The little injury that has been done to her and her family simply rests in her mind as a source of discontentment. We can wipe it out of our minds by saying to ourselves "what difference if she is discontented?" We know well, however, that the accumulation of a mass of little discontents is what causes the major misunderstandings in what is commonly called the labor world.

There is a constant pressure to take up collections in the shop. Many of the best causes appeal to the management, and it is so easy to say—yes, go in and talk to the men or encourage the foremen to take up a collection. We never do it in our factory regardless of the cause. Once a year the Salvation Army girls stand at the door and accept contributions from the men coming out.

There is an even worse practice which is prevalent. We are requested at times to abstract a sum of money from the envelopes of the employees. Sometimes the employee signs an authority requesting the employer to take a sum of money

from his pay each week and apply it to an insurance policy, or a charity. This we never do. If we owe the man $30.00 he must get $30.00, and then he can give 50¢ to somebody else if he wants to. The payroll is sacred. We agreed to pay the man $30.00 and will pay him no less, and we will not act as his agent even to collect money for his own good.

In our factory in Germany for years back there have been four different taxes for four different purposes, amounting to a substantial proportion of the man's pay, which were deducted from his envelope. The German worker has to endure this. The American workman should not be submitted to it and the American employer should steadily put his face against such practices. It has already started in this country. We appear to have no way of avoiding the Social Security Tax. We recognize that seizing this amount from the envelope is an outrageous injustice to our employees, but the Budd Company is not strong enough to resist it, and we do make this deduction.

States and municipalities which have difficulty collecting taxes, or for political reasons are afraid to take the responsibility of collecting the tax, are trying to shift the responsibility over to the employer, so the employer has to face the ignominy that always is attached to a tax collector. When we do this thing at every week-end, we stir up a feeling of resentment in the minds of the workman, his wife and even his children. The resentment is not against the government but against the employer. The employee knows we agreed to pay him $30.00 and only paid him $29.55. There should be an indignant refusal on the part of every manufacturer to this tampering with the pay envelope. It may be much cheaper for the manufacturer to pay the tax than to have his employees look upon him as a tax collector.

POLICE.

Where great numbers of men are gathered together, what is known as policing becomes a safeguard. In public halls where there are large audiences there are presumably no evil-minded people, but the very presence of the crowd, with the risk of hysteria, fire or panic, calls for the presence of a substantial number of men in uniform who are trained to meet such emergencies.

In modern factory management the police department becomes important. There has to be a company representative at the gate. He should be able-bodied and intelligent. One who has been trained in a police department has the proper qualifications. It is not that these men are braver than other men that they can be depended upon to meet emergencies, but because their training is such that what appears to be an emergency and occasion for excitement to a civilian, is not a matter of surprise or excitement to the trained officer.

So much for his mental attitude. Physically he is well built and keeps himself in fit physical condition. In case of attack he knows how to accomplish his end without undue violence. It is rarely that emergencies require the infliction of personal injury. The civilian who may become angry or unduly excited is apt to indulge in physical violence, where the trained policeman with quiet manner can better accomplish his end.

There is no class of workmen where personal character is more essential than in the policing or watching force. The presence of plenty of them is only a reasonable safeguard against emergency. The innocent man is not worried by the presence of policemen and is safeguarded. The only ones who need worry are thieves or people with mischievous intent. In case of fire or explosion, the presence of a sufficient number of these competently trained men is most important. They are quite as valuable to the company as insurance against loss from fire.

The presence of these men at the gate will prevent intrusion, and the thoughtful manager cannot overlook the fact that in recent times there have been attacks from the outside on the part of ill-advised citizens. There is small risk of this and it is the least important duty of the police force, but it is a duty which, when the emergency arises, must be met promptly, vigorously and effectively. The number necessary of course depends on the number of employees, and to a lesser extent on the dependability of the local police.

The writer has stated these problems and methods only as they are applicable to manufacturing in Philadelphia and to the class of manufacturing which we carry on in our plant.

To the extent that I have gone into details, there will be endless differences of opinion. There are a few bare principles which I believe are universal.

A factory is not a debating society. Leadership must prevail and all along the line of organization the incentive to follow the leader must be based upon the respect which the employee has in his immediate leader. The factory is divided into many divisions, and each division has a head. These heads are leaders, not drivers. The heads must have a power of leadership which assures the production of better goods at less cost than can possibly be attained by a driver.

There must be a human atmosphere throughout. The firm is ambitious to produce the best grade of goods by the best possible methods. It must secure the best workmanship. Therefore to the rank and file the pay must be something more than the market price of wages, and to all the staff there must be either handsome compensation or a prospect before them which convinces them that our plant is the best place to attain their individual ambitions.

Thermocouples Take Turbine Temperatures.—B. O. BUCKLAND AND S. S. STACK. (*Electrical World*, Vol. 113, No. 8.) Advances in the art of power generation, including higher steam temperatures and pressures in turbines for new central stations and superposed units for existing plants, have resulted in a complexity of power plant piping. This has complicated the measurement of steam flow in using the load-flow method to determine steam rate in turbine performance tests. The temperature-drop method, in which the initial and final enthalpies are established by temperature and pressure measurements, has thus increased in usefulness. To make this method more reliable, a thermocouple technique has been developed which results in satisfactory agreement between turbine performances measured by the two methods. Thermocouples were used instead of mercury-in-glass thermometers because they eliminate the necessity for making stem corrections and usually are more easily and conveniently read. While the precision obtainable with the platinum resistance thermometer is desirable, it has not been thought discreet to use this device for turbine-testing up to the present. The thermocouples are made of Chromel (90 per cent. nickel, 10 per cent. chromium) and Copnic (55 per cent. copper, 45 per cent. nickel) wires, 40 to 30 ft. long between cold and hot junctions. Continuous wires are used to prevent errors due to temperature gradients at connection points. Two methods of making the hot junction are used—uninsulated and insulated. Cover for the round lead is tellurium-compounded rubber to make it waterproof and oil resistant. Test data using the thermocouples show that independent measurements of steam temperatures at a turbine throttle agree within ½° F. or less at 900° F. and similar measurements at the turbine exhaust agree within 1° F. or less at 600° F.

R. H. O.

A PLANNED MARINE MUSEUM.

BY

CHARLES MERRICK GAY,

Associate Director, Marine Transportation,
The Franklin Institute Museum.

The sea has performed two quite opposite and contradictory functions. It has afforded the simplest means of communication among the peoples along its shore, yet has isolated from each other whole continents and races. Long before roads were built, water rendered transportation possible between coastal cities on the Mediterranean and Red Seas and along the eastern Atlantic. On the other hand, India, China and America were long unknown to European nations because of the tremendous oceans which separated them.

Seacraft may, then, trace their development according to the demands upon them. At first, adapted only for short coasting trips with light loads, they increased in size and efficiency as cargoes became heavier and inter-communication more insistent. Finally, as the demand for the products of the East expanded and the spirits of science and adventure unfolded, ships capable of navigating the great Atlantic and Pacific oceans were evolved. Thus the detachment of large portions of the earth was terminated. The sea no longer isolates the peoples upon its shores but rather contributes a facile medium for transportation and communication.

Ever since the 17th century, North America has contributed a significant share in this development of marine craft and in the penetration of unfamiliar seas. To most Americans the ocean and its ships make a peculiar and innate appeal. This is particularly true at the present time. The people have awakened to an understanding of the imperative importance of marine transportation and protection. The Government is rapidly increasing the Merchant Marine and the Navy.

There has been, however, a natural tendency on the part of the public to neglect the story of the ship's structure and

the methods of her propulsion and control through the various stages of progress. The knowledge of what modern vessels are and through what phases their construction and navigating advanced adds a vividness to the widespread but, perhaps, hazy conception of their importance. Education in these respects is a social, political and economic necessity and not merely an intellectual diversion. It has a direct influence upon the industries involved.

It seemed to the management of the Museum of the Franklin Institute in Philadelphia to be of first importance, in planning their Hall of Marine Transportation, that the exhibits should illustrate the course of development of American maritime art from the days of the discovery of the continent to the present time. It was likewise considered to be of first importance that the collection should contain examples of the chief types of ships and navigating equipment of our own day. In this way, information and instruction may be presented to the general public in regard to modern shipping and the latest marine equipment, together with systematic indication of the stages which have led from past to modern practice.

The perfecting of marine transportation has depended upon a broadening knowledge of shipbuilding and design, of navigation and of the motive power of engines and the wind. The exhibits in the Franklin Institute are, therefore, divided into four sections: Sail, Steam, Navigation and Shipbuilding. They are limited to examples related to North America.

A. SAIL.

The energy of the wind was the first motive force employed, after man power, to drive ships on their desired courses. Hence the first sails were naturally simple and few in number. Such were the ships which, steered by love of adventure or by the desire for a shorter route to India, ventured across the Atlantic and found the new continent of America. The model of the *Viking Ship*, carrying a single square sail for fair winds and still largely propelled by oars, represents the sort of craft visiting this country in the 9th century; and the *Santa Maria*, with more masts and sails and depending entirely on wind for locomotion, is typical of the Mediterranean merchant ship in

which it is supposed Columbus crossed the Atlantic in the 15th century.

As the vast possibilities of American settlement became understood during the following years, many vessels brought hundreds of colonists across the sea. They showed greater depth of hull for cargo space and for working to windward, greater ease in handling and, consequently, higher efficiency. *The Mayflower*, carrying the Puritans to Plymouth in 1620 and William Penn's *Welcome* of 1682 are examples of the colonists' ships of the 17th century. It will be noticed that both these vessels carried square sails beneath the bowsprit to assist in steering and that no fore and aft jibs or staysails had yet been employed.

Water furnished the easiest and quickest means of communication and transportation among the fast growing settlements along the coast and the great rivers of North America. The building of ships, therefore, arose as one of the first activities of the colonists. Trade was begun from Maine to Georgia and with the West Indies. During this time, the fore and aft rig began to be seen. It may be distinguished from the square rig in that the sail hangs along the ship from a spar pivoted at one end to the after side of the mast. The wind may, therefore, be received on either side of the sail. The square sail, on the other hand, hangs across the ship from a spar pivoted at its center to the fore side of the mast. The wind, consequently, always strikes on the after side of the sail. In general, it may be said that the fore and aft rig, because of its weatherliness and ease of working with small crews, is more adapted to coasting and river craft. As ships become larger, square sails are found safer, less laborious to handle and more appropriate to deep sea voyages. With some exceptions, then, American vessels in the coasting and West Indian trades were fore and aft rigged, while ocean-going craft were furnished with square sails on two or three masts. The fore and aft sloop *Ferret* is an example of a popular type of colonial craft of the early 18th century.

As the population and products of the colonies increased, larger vessels were built, square rigged ships, barques and brigs and fore and aft sloops and schooners, until at the time of the Revolution, American yards were producing excellent

craft of all kinds, such as the frigates *Hancock* and *Raleigh*, and the brig *Philadelphia*. After Independence was established, shipbuilding progressed rapidly with great advances in design and rigging. The War of 1812 found the United States with a small but efficient, well-equipped and fast-sailing navy, of which the *Constitution* is a good type, and the built-up model of the *Constellation* an excellent example. These frigates had flush decks throughout their length in place of the previously raised forecastle and quarter-deck, and were

Sail. Series of early ships. Clippers. "Welcome" in center.

more heavily armed than the average foreign ships of their class. They combined speed with great striking power. *Gunboat No. 5* represents a type of 50-foot craft favored by President Jefferson to patrol our coasts and rivers. The *John Adams* is a frigate of 1830.

After peace was declared in 1815, shipbuilding received a tremendous impetus from the expanding commerce with Europe and the Orient. Slow-moving convoys were no longer required. Speed and dependability, demanded by passenger service and valuable cargoes, were so increased that fixed

schedules of arrivals and departures were maintained in Boston, New York, and Philadelphia. Refinement of lines, light construction and improvement in sailing ability were particularly developments of American shipping, first in the Packets with their regular runs to England and France, and in the 1840's and 50's by the Clipper ships with their record-breaking voyages to Europe, China, India and California. Examples of the clippers, considered the perfection of square rigged craft, are the *Flying Cloud* and the *James Bains*. They proved, however, not commercially economical and less extreme ships, such as the modified clipper *Winona*, took their place. A heavy cargo vessel of the 70's is shown by the *Star of the South* and a four-masted barque by the *Frederick Billings*. Fore and aft schooners are represented by the revenue cutter *Gallatin* of 1830 and the yacht *Wanderer* of 1857.

But as the sailing ship reached perfection, her rival, the steam vessel, was rapidly maturing and, because of greater capacity, speed and reliability, finally displaced her. By 1900 sail had virtually disappeared.

Along with the development of the more generally accepted types of vessels, many individual craft were brought forth with peculiarities of hull and sail design adapted to special uses or localities. Such were the fishermen, whalers, trawlers, and oyster boats and the New England, New York and Chesapeake Bay craft which flourished for longer or shorter periods. They are illustrated by the Gloucester fisherman *Columbia*, the oysterman *Mabel*, the Hudson River sloop *Experiment*, the *Whale Boat*, the *Skipjack*, and the *Bugeye*.

Yachting was initiated in the early 19th century and received great impetus by the success of the schooner *America* in winning an important race in England in 1851. She brought her cup to this country and many efforts have been made by the British to win back the trophy. The changes in hull and sails of the defending yachts may be realized from a study of the models of *Mischief* of 1881, *Puritan* of 1885, and *Enterprise* of 1930, and from the Table showing the hulls and sails of all the defenders, including *America*, from 1851 to 1930. These changes especially improved speed, handiness and sailing to windward, and reduced weight and resistance to air and

water. The present great interest in sailing as a sport is illustrated by the models of the popular one-design and rating classes, *Midget*, *Suicide*, *Comet*, *Star* and *Six-Meter*, and of the ketches *Typhoon* and *Grampus*. The set of 25 lithographs by Cozzens show the important yachts of this country up to 1884.

B. STEAM.

Experiments in the use of steam as a motive power for ships began in the latter part of the 18th century. Fitch in 1787 and Fulton in 1807 constructed boats driven entirely by steam engines which made scheduled runs of short distances on the Delaware and the Hudson. Models of these craft with their engines in operation are seen in Fitch's *steamboat* with laterally placed oars and in Fulton's *Clermont* with side paddle wheels. In 1808 Steven's *Phoenix* emerged into the ocean with trips between New York and Philadelphia. As time passed, marine engines became more efficient and voyages more ambitious until in 1819 the *Savannah* crossed the Atlantic, partly under steam and partly under sail. In 1844 the Cunard Line instituted regular Atlantic crossings with the steam and sail driven *Britannia*. Increase in size, speed and engine power followed rapidly, the assistance of sail was discarded, and today we have the fast passenger liners *Champlain* of 29,000 tons, *Bremen* of 51,656 tons, *Berengaria* of 52,700 tons, and *Queen Mary* of 81,235 tons. Many types of steam and motor driven vessels have appeared, adapted for various purposes, the freighter *Crown Point*, the sidewheel Sound steamer *Mount Hope*, the Pennsylvania schoolship *Annapolis*, the stern wheel Ohio River steamer *Tom Greene*, the oil tanker *J. W. Van Dyke*, the ferry boat *Princess Anne*, the light ship *Nantucket*, ore boats, tugs, trawlers and colliers.

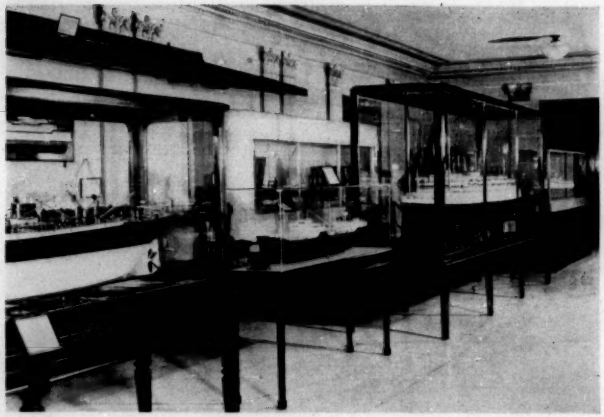
The increase in size, speed and dependability of steam vessels was made possible by the vast improvements in power and efficiency of the marine engine, by the rise in steam pressures and temperatures and by the changes from paddle wheels to screw propellers and from wood to steel construction. The earliest engines operated at not more than 5 pounds pressure and 220° F. steam temperature. By improvements in boiler design, lubricants, condensers, and superheaters, steam pressures have been raised to 625 pounds per sq. in., and steam

temperatures to 920° F. Thus the advances were made possible from the simple expansion one-cylinder engines of Fitch to the compound and triple-expansion engines of our time. Here, the expanded exhaust steam from the smaller high-pressure cylinders is used again in the larger low-pressure cylinders with great conservation of energy and economy of fuel. Each cylinder functions as a part of the engine and not independently of the others.

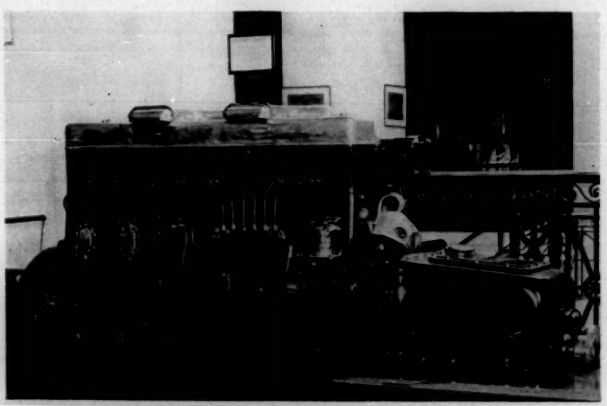
Until 1894, marine engines were of the reciprocating type in which the piston moves in one direction, comes to a rest

Steam. Passenger ships and early steamships. Marine engines.

and then moves in the opposite direction, the inertia of the reciprocating parts limiting the practicable speed. Late in the 19th century, the turbine appeared, consisting of a drum free to rotate continuously within a casing. The drum is revolved by jets of steam projected upon rings of blades fixed to its surface. The steam passes from the high pressure to the low pressure turbines as it expands, is condensed and returns as water to the boilers. Above 2,000 to 3,000 horse power the turbine produces higher speeds and is more economical in coal consumption than the reciprocating engine and is



Steam. Freighter, tanker and passenger ships.



Steam. Marine Diesel engine.

now generally used in the larger ships. It may be employed directly or through reduction gearing to drive the propeller shaft, or to operate an electric generator which, in turn, supplies current for motors connected to the shaft.

Models may be studied of the transition from the simple engines of Fitch, Fulton and Stevens, through the one-cylinder reciprocating, the walking beam, the compound and the triple expansion to the steam turbine.

The very extensive use of motor boats, both commercial craft and pleasure cruisers and speed boats, has been made possible by the perfection of the internal combustion engine. Here are found two major innovations. The power arises within and at only one end of the cylinder and is produced by the explosion of a mixture of fuel and air. Firing may be obtained by auxiliary ignition as in the case of the gasoline or kerosene engine, or by self-ignition through the heat of compression as in the Diesel engine. In the former a mixture of air and fuel vapor is fired by an electric spark or by the use of a hot bulb. In the Diesel, oil is forced into the cylinder through a spray nozzle and air is admitted at the same time. The resultant mixture is so highly compressed by the movement of the piston that sufficient heat is produced to ignite it. The power stroke results from the rapid combustion and consequent expansion against the piston. Examples are shown in the early make and break spark engine, the six-cylinder gas engine for large cruisers, and the smaller four-cylinder engine. Outboard motors are also illustrated in the early cast iron and the modern aluminum alloy machines. A full size Diesel engine of 170 horse power is also on display.

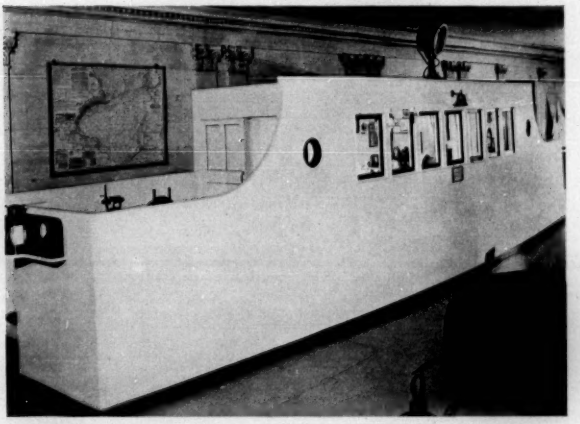
C. SHIPBUILDING.

The experience gained in progressing from coasting trips to transoceanic voyages and the ever increasing demand for larger, faster and more seaworthy vessels naturally produced definite developments in the arts of ship design and shipbuilding.

For the days of sail and wooden hulls the models on display show clearly the advance from the early heavily built sluggish hull and unwieldy rigging of the *Santa Maria* to the graceful, speedy, fine-lined forms and light and efficient rigging of

clippers. These improvements were attained by better knowledge of wood framing, of buoyancy and stability, of the effect of water resistance on various shapes of hull, of wind action and of the mechanics of blocks and tackles. Greater speed, increased weight carrying and the ability to head closer to the wind, together with dependability and seaworthiness, were the results. Naval architecture became an art and shipbuilding a science.

The shipyard of the late 18th century serves as a setting for the built-up models of the *Hancock* and the *Constellation* and



Navigation. Pilot house and bridge.

illustrates the various activities connected with the construction of a wooden ship. These methods changed very little throughout the 18th and 19th centuries. The large model of the *Star of the South* presents all the sails, standing and running rigging of a full-rigged ship. Two large panels illustrate the knots and splices commonly used by sailors. The figure-head of the *U. S. S. Franklin* is an interesting example of this type of ornament.

At the present time the design of sailing craft is largely confined to fishermen, yachts and pleasure boats. The con-

tinued studies of water, wave and wind action and methods of streamlining masts, spars and rigging have produced great improvements in speed, handiness and weathering qualities, as illustrated in the yacht models and the fisherman *Columbia*.

The change to steam propulsion and to steel fabrication has naturally altered in certain respects the field of modern naval architecture. Water resistance, wave action, stability, buoyancy and weight carrying are, as ever, of great consequence but the development of the marine engine and the adoption of riveted and welded steel as a building material have assumed a first importance in the activities of the ship designer and ship builder.

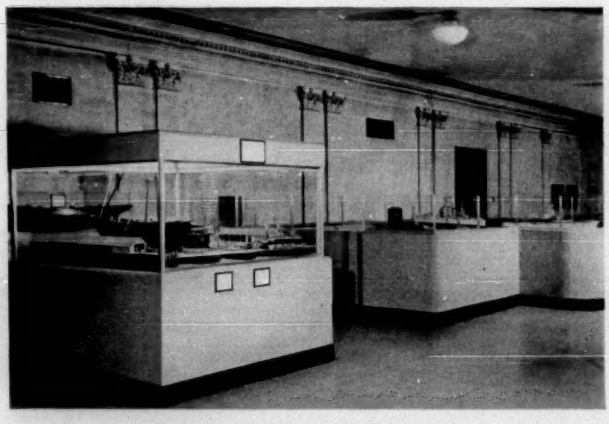
The large water tank contains a model of a yacht controlled by radio from outside. In the tank it is also proposed to exhibit models of a floating dry dock and a ship launching, together with demonstrations of water resistance, propeller design and wind action on sails. Cross section models of steel ships showing both the transverse riveted and the longitudinal welded methods of framing are planned. Half-models of wood and steel hulls demonstrate the methods of determining the curves of the frames of the hull and the shapes of the steel shell plates. Two cases, with over twenty small models in each, trace the developments in the British and American navies respectively from the earliest miniature sailing craft to the modern tremendous battleships and airplane carriers.

D. NAVIGATION.

The safe and intelligent guidance of a ship and the true knowledge of her position, both when near the shore among reefs and shallows and in the open sea beyond sight of land has always been the first care of a mariner. In the early days paths could be followed only by experiment and true positions were problematical. As navigation advanced, however, coast oulines with water depths and currents were charted, buoys were set and sounding machines invented. And in the open sea the methods were gradually evolved of finding the exact place of any ship with accuracy and dispatch.

When in sight of shore, a vessel's position may be determined by measuring the water depth or sounding and by taking cross bearings on light houses, church steeples or other

salient objects marked on the chart. By reference to the chart the position may then be found. The safe channel is outlined by buoys, and other markers give notice of reefs and obstructions. At night the position may be found by soundings and by reference to light houses, light ships and lighted buoys. The model of a Water Way between two shores demonstrates the use of light houses, can, nun, spar, bell, whistling and flashing buoys and lighted channel markers, both by day and night.



Shipbuilding. Yard for building wooden ships. Water tank with launching model and radio controlled yacht.

When beyond the sight of land, a ship's position is calculated by obtaining its latitude or number of degrees north or south of the equator, and its longitude or number of degrees east or west from the observatory at Greenwich, England. The former is attained by the use of the sextant, a nautical instrument by means of which the altitude of the sun, moon and stars above the horizon may be measured. The latter is given by the difference in observed time on board ship and the chronometer time in Greenwich. In recent years radio beacon transmitting stations have been established at frequent inter-

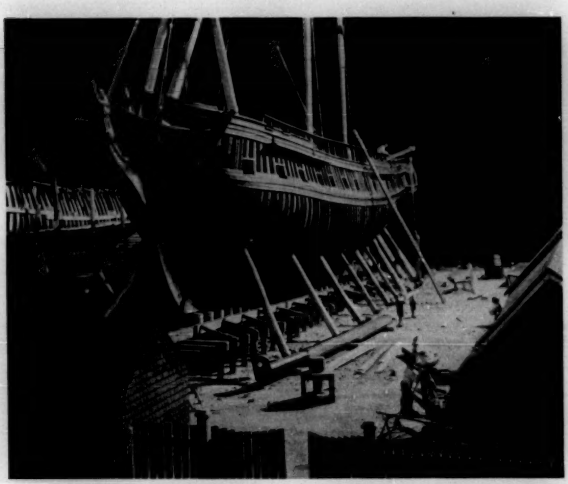
vals along the coasts of Europe and North America. By an instrument known as a radio direction finder the bearing of the ship from two or more transmitting stations may be received. The ship's position will then be at the intersection of the bearings as plotted upon a chart. These beacon installations are of great value in general to check observations and time particularly in foggy or cloudy weather when sextant sights cannot be obtained.

Shipbuilding. Ship careened for cleaning and repairing.

The great standby for determining courses through many hundred years has been the magnetic compass. The needle points to the magnetic north and not to the true or geographic north and a correction must be applied to overcome this variation whose amount differs according to location on the earth. Likewise the deviation caused by the attraction of iron and steel material on the ship may result in further departure of the needle from true north. For these reasons the

gyroscopic compass and pilot which acts mechanically and not by magnetism, has been lately developed and widely adopted. It points to the true north, may be electrically connected to repeater compasses in any part of the ship, and can be set to keep a vessel automatically on a given course.

Soundings were first taken by throwing into the sea a lead weight attached to a cord, the depth of water being measured by the amount of cord submerged when the weight rested upon



Shipbuilding. "Constellation" on the building ways. Shipwright shops.

the bottom. Various sounding machines with revolving reels and wire ropes have been invented. The most perfect development is the fathometer which transmits sound to the sea bottom and measures electrically the time required for the echo to return to the ship. The depth in fathoms is then indicated upon a dial.

The first speed indicator was the chip log and line consisting of a thin piece of wood, weighted to float upright, attached to a line marked off at equal intervals. The log is thrown

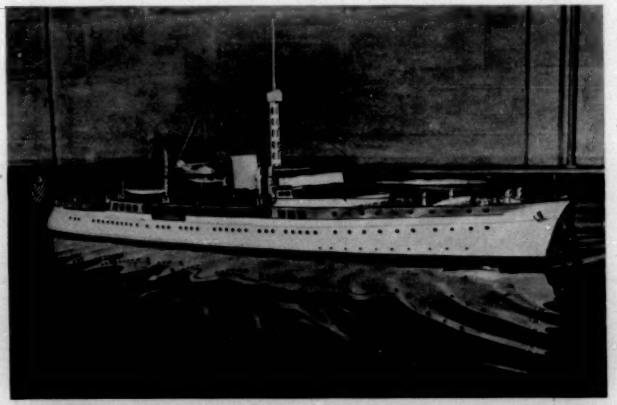
overboard at the stern and rests in place in the water, the amount of line unwinding in a given time from the reel, as the ship moves away, indicating the distance traveled in that time or the speed. Patent taffrail logs have superseded chip logs and consist of a rotator with radial blades towed behind a ship and a line communicating the turns of the spinning rotator to an indicator fastened on the stern of the vessel. The indicator is calibrated to register nautical miles. Devices are also

Shipbuilding. Framing the timbers. Shipsmith shop. Counting house and mould loft.

manufactured which measure the speed by water pressure on the hull and indicate the rate electrically in miles per hour upon dials in any part of the ship.

A full-size pilot house and bridge have been constructed, which house the navigation equipment found in a modern steamship. The steering wheel and magnetic mariner's compass and binnacle occupy the central portion. Directly beside them are the gyroscopic repeater compass and automatic pilot. Either steering method may be used at will. Two engine

telegraphs for sending speed signals to the engine room flank the wheels. A course recorder, rudder indicator and engine indicator show the trace of the ship's course as she proceeds, the angle of her rudder and the speed and direction of her engine. A direction finder for receiving radio bearings is on the starboard side, a clinometer and the indicator, amplifier and resistance unit of a fathometer are on the after wall. A chart table stands on one side and on the other a signal flag locker carrying aneroid and recording barometer.



Shipbuilding. Radio controlled yacht in water tank.

A case of nautical instruments is also located in the Navigation section. Here are exhibited a chronometer for accurately keeping the Greenwich time; a mariner's boat compass in its box; chip, harpoon and taffrail logs; an artificial horizon for use when the true horizon is not available; a stadimeter for measuring the horizontal distance to a point whose height is known; magnetic force instruments; binoculars; telescopes; a signalling pistol; reading glass; ship's trumpet; protractors; drawing instruments; parallel rulers; and a log book of the U. S. S. Bainbridge.

The sailing and steam ship models have been built from the authentic lines of the vessels they represent. The only exceptions are the *Santa Maria*, the *Mayflower*, and *Welcome*. The first of these was constructed as a late 15th century ship of the Mediterranean type and the last two as English 17th century merchantmen. Where possible, the same scale, ¼ inch for sail and ⅛ inch for steam, has been maintained.

The marine library contains 1,500 volumes including the early works on the sailing ship and the latest writings on steam, marine engines, navigation, naval architecture and yachting. The collection of original draughtsman's plans of naval ships from 1797 to 1865 of Chief Naval Constructor John Lenthall are the property of The Franklin Institute and are available to students.

The scheme of the Hall of Marine Transportation, followed from its inception, is to offer a detailed view of modern attainments in sail, steam, navigation and shipbuilding. While not an historical museum nor a depository for relics of the past, a systematic showing of the successive stages of development is considered of parallel value in the intelligent grasp of the subject. The planned Museum, then, becomes a methodical exposition of the successive steps of progress through the past and a logical presentation of the achievements of the present.

The Luximeter.—W. L. CARSON. (*General Electric Review*, Vol. 43, No. 2.) The luximeter is a photoelectric instrument for measuring light transmission through a liquid. It has a wide field of usefulness in such applications as the following, pasteurization of milk, biological determinations, chemical analysis, physical listing of oils, etc., determination of free chlorine in water, process control in industrial plants. The instrument employs a photoelectric cell or electric eye which together with its associated indicating element replaces the human eye in the measurement of light transmission, so that distinct readings are obtained instead of uncertain matchings or estimates of the factors involved. Heretofore the human eye was depended upon for differentiating the intensity of colors. While good results were obtained, limitations were encountered because of the variations in the eye with different individuals, and favorable lighting conditions were a necessity; hence eye colorimetry did not always give the desired accuracy. The photoelectric cell, although more sensitive to the blue end of the color scale than the red, measures only the degree of transmission of light. Thus the variations of the human eye are not inherent in the photoelectric cell and the accuracy of the cell approaches that of an electrical measuring instrument. The luximeter consists of a lamp which can be maintained at a constant light intensity, a test tube holder, and light meter, all mounted in a small Textolite case. The individual parts are so arranged that light from the lamp passes through a test tube containing the liquid to be measured, then to the photoelectric cell which actuates a sensitive indicating instrument.

R. H. O.

IONIZATION MEASUREMENTS OF THE RADIATIONS FROM RADIOACTIVE SUBSTANCES.

BY

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INTRODUCTION.

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The rapid advance in the art of the transmutation of the elements has caused in recent years a remarkable revival of the interest of physicists in the science of radioactivity. There have been, meanwhile, many improvements in the technique and the methods of measuring amounts and activities of radioactive substances. Of prime importance is a knowledge of the ranges of usefulness and the limitations encountered in the use of ionization chambers to measure the radiations. We propose to discuss here some aspects of these problems. Most of the material pertinent to the problems is unavailable except in widely scattered sources, and although little that is original is presented below, it is hoped that the collection of some of the information will be valuable to many workers.

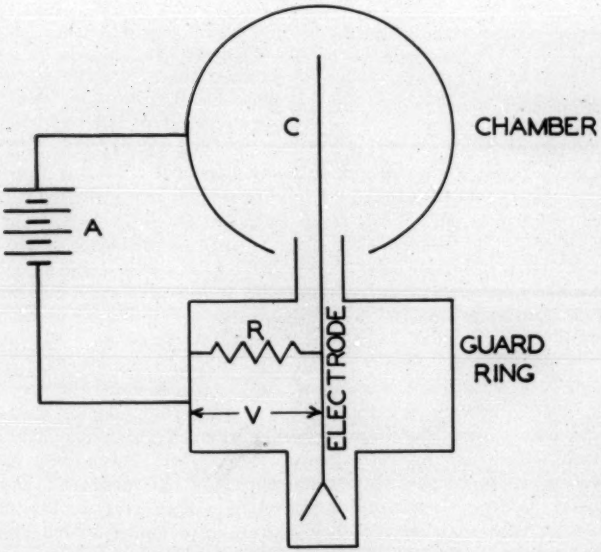
Following an outline of the methods of construction of ionization chambers in general, and a discussion of some of the precautions to be taken, the limits of sensitivity are calculated for a particular chamber used in conjunction with several kinds of measuring instruments. Separate discussions are presented concerning the measurement of the ionization produced by alpha, beta, and gamma rays, respectively. The results of these calculations are expressed in tables which give the smallest number of alpha, beta and gamma rays, per second, in this particular chamber, which can be detected by means of the instrument in question, the limiting factor being either the sensitivity of the instrument or the fluctuations in the residual ionization of the chamber. The corresponding limits for other chambers can easily be calculated in a similar fashion. When the chamber is small and the sensitivity large,

other factors become important in setting the limitations, namely, the discreetness of the electronic charge and the thermal motions of the electrons. These factors are discussed briefly. A short bibliography is included.

METHODS OF OBSERVATION OF THE IONIZATION IN A CHAMBER.

An ionization chamber assembly consists essentially of four parts: (1) the collecting volume or ionization chamber

FIG. 1.



Schematic diagram of an ionization chamber assembly.

proper, (2) the guard ring, (3) the electrode system on which are collected the ions, and (4) some measuring instrument to determine the change in potential of the electrode system when the ions are collected. In Fig. 1 are schematically represented the electrical connections of the essential parts of an ionization

chamber. We may choose our point of zero potential arbitrarily, since constant potential differences do not matter, and for the purposes of this discussion let us choose the guard ring as this point. Let V be the potential of the electrode system, R the resistance between the electrode system and the guard ring, C the capacity of the electrode system, and I the number of ion pairs which are collected per second. If the source of ionization is brought near the chamber at the time t equals zero, V is given by equation (1):

$$V = IeR[1 - \exp(-t/RC)], \tag{1}$$

where e is the charge on an ion and is equal to 1.6×10^{-19} coulombs. When the source of ionization has been present for a long time, the potential thus reaches a steady value which corresponds to some steady deflection of the observing instrument. This steady value is $V = IeR$ and is independent of the capacity of the electrode system. When observations of this quantity are made, we speak of employing the "steady deflection method" of observation. If RC is large, and we do not wish to wait for a long time, then we may measure the rate of change of potential which is

$$\frac{dV}{dt} = \frac{Ie}{C} \exp(-t/RC). \tag{2}$$

This reduces to

$$\frac{dV}{dt} = \frac{Ie}{C} \tag{3}$$

for times which are small compared to RC, and is thus independent of the resistance. Care must be taken, in the latter instance, that the dynamics of the electrometer shall not influence the results. If a sluggish instrument is used, or one which is not sufficiently well damped, readings must be taken at intervals such that the deflection represents the actual voltage applied to the instrument. Obviously, as in the steady deflection method, the total time interval during which the electrometer deflection is observed must be long compared with the period of the instrument.

Whether the steady deflection, or the rate of change of potential, is observed our measurements represent a comparable change of potential of the electrode system, so that it is evi-

dent, since time can be measured with a negligible error, that it is possible to achieve the same precision by either method in so far as this is influenced by the measuring instrument itself. However, to use the steady deflection method, we must know the value of R in order to interpret the observed deflections in terms of ion pairs formed per second. If we use the second method, we must know the value of C. Since R is in general much easier to measure than C, the first method is more convenient and we shall consider in what follows only this method. The conclusions reached will, however, not be restricted by this choice but apply equally well to the second method of measurement.

There is a third method of observing a quantity of ionization which is useful in some special applications. The electrode system may be allowed to charge up as it collects ions, for a definite time. It is then connected to the measuring instrument either directly or by utilizing an electrostatic induction method. The ballistic throw of the measuring instrument is then observed. This method is considerably more difficult to use and, since it is not capable of very general application, we shall not discuss it further here.

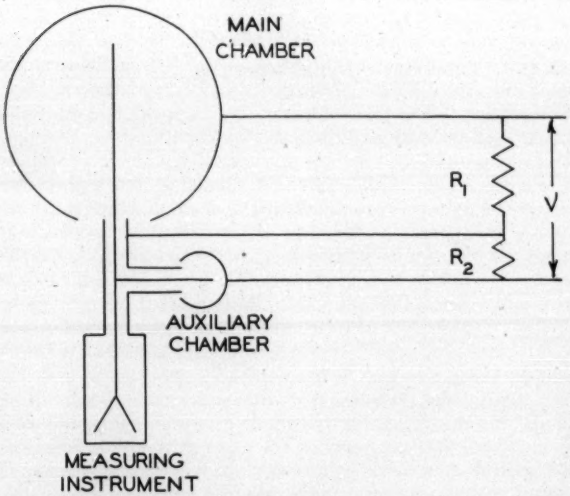
COMPENSATION OF IONIZATION CURRENT AND BATTERY FLUCTUATIONS.

In some applications of the use of ionization chambers, for example in the measurement of long-period fluctuations of the ionization from cosmic radiation, the time RC may be very long, and yet it may be inconvenient to use the rate of change of the electrode potential as a measure of the ionization current. In such cases it is possible to balance the ionization current which it is desired to measure against some other small current, a photoelectric current for example. A small auxiliary chamber containing a radioactive substance of long life may also be used. Figure 2 shows schematically how this may be accomplished. The particular application in mind will dictate the details of the arrangement which it is best to use.

It will be noted from Fig. 1 that any change in the potential difference across the battery A will be reflected in the measuring instrument, and it may be necessary to introduce some form of compensation for this. This may be done by the use

of an auxiliary chamber in the manner shown in Fig. 2. If the resistances R_1 and R_2 are so adjusted that they are inversely proportional to the coefficients of induction of the main and auxiliary chambers to the electrode system, then a change in the potential V will leave the electrode potential unaltered. In testing the adjustment of the resistances, it is well to do so by reversing the polarity of the potential supply

FIG. 2.



Schematic diagram of an ionization chamber assembly with compensation for ionization current or battery fluctuations.

rather than by increasing the voltage from zero to some other value, since in the latter case the collection of the ions which have accumulated in the chambers in the absence of the field will produce a deflection of the measuring instrument. In the absence of complete saturation, a change of V, even from one high value to another, will produce a change in the equilibrium concentration of the ions within the chambers. By adjusting the resistances so that reversal of the potential pro-

duces no deflection, however, the balance may be made very accurately, and complete compensation may be attained.

If a quadrant electrometer is employed, it is possible by tapping off of the resistances R_1 and R_2 in the proper places, to effect compensation for changes in the needle potential in a similar manner. There are, however, disadvantages in using such a system of compensation. It is necessary to have a source of potential higher than would be used otherwise, since only a portion of it is actually applied to the ionization chamber. Moreover, sources of high potential are by nature generally unable to deliver large currents, so that the resistances R_1 and R_2 must be high, and the leakage resistances which are effectively in parallel with them must be correspondingly higher and of great constancy. Suppose, for example, that $V = 2000$ volts and $R_1 = R_2 =$ one megohm. If we are using a measuring instrument of a sensitivity of 1000 divisions per volt, a change in R_1 by the appearance of a leakage resistance effectively in parallel with it of even as much as 10^{12} ohms will produce a deflection of the order of one division. Thus, the insulation of all parts of the apparatus must be extremely good. To accomplish this, blocks of sulphur are extremely useful in supporting the apparatus and remain excellent insulators under conditions of high humidity, or when they become so dirty that one would suspect them of being good conductors. It is much easier to attain low leakage if no point of the system is actually connected to earth. The potential of the apparatus as a whole does not affect, of course, the potential *differences* inside the apparatus which are actually measured. For a great many purposes, however, it is unnecessary to take such precautions. Standard radio "B" batteries are very stable potential sources in respect to changes which occupy only a short time, of the order of the period of the measuring instrument. To get the best results, batteries of low internal resistance should be used and they should be kept well insulated so that leakage resistances will not affect the potential. A fractional rate of change of potential of less than one part in ten million per second can easily be attained.

THE GUARD RING.

The guard ring of an ionization chamber assembly performs an important function, and is essential except in the simplest

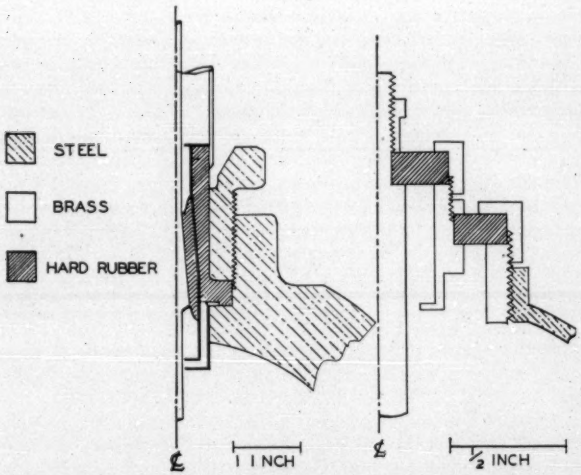
type of chamber, where the measuring instrument is inside the chamber proper and serves also as the collecting electrode. The common form of gold-leaf electroscope is of this type, but it is not especially suitable for accurate measurements or the use of high sensitivities. Results of high precision are, however, possible to obtain by the use of well designed apparatus, such as the cosmic-ray ionization chamber of Millikan and Neher; and quite high charge sensitivity has been realized by reducing the capacity of the electrometer, as in the case of the useful Lauritsen electroscope. The first function of the guard ring is to protect the electrode system from leakage currents which might flow across the insulation. It was for this purpose that guard rings were originally introduced. However, with the high grade of insulators now available this function becomes a minor one except in special cases. The second purpose of the guard ring is to provide electrostatic shielding for the electrode system. No lines of electric force must connect the electrode system to anything which is not at a fixed potential with respect to the guard ring, since otherwise the changes of potential of external objects will change the potential of the electrode and introduce spurious effects. The third purpose of the guard ring is to avoid the occurrence of some troublesome phenomena which are connected with the electrical polarization of the insulators, and its relaxation. There must necessarily occur somewhere in the apparatus an insulating material which is in a strong electric field produced by the potential which is employed to collect the ions. An insulator in an electric field will behave erratically, particularly if the insulator is also subject to large mechanical stresses as is the case in ionization chambers filled with gas at high pressure. The surface of the insulator under these conditions will sometimes behave as though large charges were continually formed and dissipated there, and if there are any lines of force which pass between the surface of the insulator and the electrode, the electrode potential will suffer erratic fluctuations. Occasionally these fluctuations will die out in time. However, when a guard ring is present, it is easy to attach shields to it in such a way that charges on the insulator surface will not affect the electrode potential, and this procedure is to be recommended. This precaution is not always essential, for

many ionization chambers do not show the phenomenon, at least at the sensitivities at which they are employed.

CONSTRUCTION OF INSULATED PRESSURE SEALS.

The use of high gas pressures in an ionization chamber introduces some complications in the construction of the chamber, since the insulating materials must have suitable mechanical properties for the withstanding of high pressures.

FIG. 3.



Two methods for bringing a highly insulated electrode out of a chamber at high pressure.

Sulphur, which is the best insulator from many points of view, and which may be employed with excellent results in ionization chambers at atmospheric pressure, is, of course, unsuitable and other materials must be employed. To illustrate the methods which may be employed, Fig. 3 shows the construction of two kinds of plugs, which have been used successfully at the Bartol Research Foundation, for bringing out a highly insulated connection from a high pressure chamber. One of

the best materials to use for insulation is hard rubber. The volume resistivity is large and the surface resistance may be greatly improved by coating with a thin layer of paraffine. When hard rubber is subjected to pressure, it will flow and consequently very gas-tight seals can be made. Changes of temperature are, of course, likely to affect the tightness of the seal, but these may be minimized by the use of conical surfaces of contact as are indicated in the figure. Many of the recently developed plastic materials are also excellent for high pressure insulating seals.

One of the most annoying sources of trouble with ionization chambers is the presence of fine fibers, sometimes so small as to be almost invisible, which will be lifted up by the electric field and stretched across the interior of a chamber when the potential is applied. Before assembly all parts should be passed through a flame to burn off such fibers as may be present.

RECOMBINATION OF IONS.

The number of ions which reach the electrode of an ionization chamber per second is not, in general, equal to the number of ion pairs formed within the vessel. Some recombination of the ions takes place. The rate of recombination is determined by the number of ions of both signs present in each unit volume, and by the pressure, field strength, temperature, and the nature of the gas. The amount of recombination therefore depends upon the nature of the radiation traversing the vessel. The ionization by alpha rays, which occurs in narrow, densely ionized regions, suffers much more from recombination than that produced by beta particles, and indeed it may be doubtful that complete saturation has ever been attained for alpha rays. Fortunately it is possible to employ fields sufficiently high so that a practical saturation is reached and accurate comparison measurements are possible. In any experimental arrangement it is essential to determine how much the degree of saturation influences the results. The ionization by beta particles may be collected much more easily, even at high pressures. Since the range of a beta particle is generally longer than the dimensions of the chamber, higher pressures result in the production of more ion pairs per particle. With

a field strength of the order of 100 volts per centimeter, pressures of argon up to twenty-five atmospheres may be used without serious recombination. The use of a high pressure has the additional advantage of suppressing by recombination the ionization of the natural contamination alpha particles which are emitted from the walls of the chamber, to the extent that their contribution to the total ionization in the vessel may be made negligible.

MEASURING INSTRUMENTS FOR USE WITH IONIZATION CHAMBERS.

In choosing the proper instrument for an investigation, a consideration of the sensitivity is of prime importance, and we wish to indicate in the following paragraphs the limiting sensitivity of an ionization chamber when used with each of a

TABLE I.

Representative Instruments for Use with Ionization Chambers.

No.	Instrument.	Period, sec.	Sensitivity † divs./volt.	Divisions for 10^6 ion pairs/sec. when the ionization current flows through 10^{12} ohms.
1	Gold leaf electroscope	1	0.1	0.016
2	Double fiber electroscope	0.1	0.3	0.048
3	Single fiber electroscope	0.1	30	4.8
4	Lindemann electrometer	5	100	16
5	Quadrant electrometer	10	1000	160
6	FP54 & 300 megohm galvanometer	3	2500	400
7	FP54 & 10^4 megohm galvanometer	14	82,500	13,200
8	RCA 38 & 300 megohm galvanometer	3	5000	80*

* With 10^{11} ohms grid resistance; see text.

† One division is taken to be the least count of the instrument. There is some ambiguity in speaking of sensitivities in this way, instead of defining them accurately in terms of the scale distance, magnification, and so forth. However, the sensitivity can be changed by only a small factor by changing these conditions, and we can neglect this since we are interested only in representative values.

number of typical measuring instruments, in order to show what limitations exist in each case and by what these limitations are caused. The choice of a suitable measuring instrument may depend not at all upon its sensitivity, but on some entirely extraneous factor. For example, a vacuum-tube electrometer is always employed with very low voltages on the electrodes of the tube. This means that it will be very

sensitive to magnetic fields, since slow electrons are very readily deflected, and the tube characteristics may be greatly changed. Thus the presence of such fields may rule out entirely the vacuum-tube instruments. Also, radio-frequency fields of oscillators such as are employed in cyclotrons affect vacuum-tube electrometers strongly while electroscopes are almost unaffected. It is, of course, possible to shield the apparatus from such disturbances, but the difficulties involved may outweigh the advantages in the use of the instrument. It is impossible to make very useful or general statements about such matters, and we shall assume in what follows that all extraneous influences are absent.

Some typical measuring instruments, their periods, and voltage sensitivities are listed in Table I. The first five instruments are of the electroscope type, while the last three entries

TABLE II.

Approximate Characteristics of Vacuum Tube Electrometers.

The circuit diagram is given in Fig. 4.

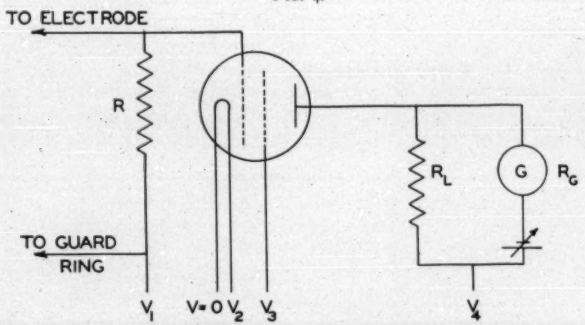
Vacuum tube.	FP54.	RCA 38.
Grid resistance, ohms	10^{16}	10^{12}
Mutual conductance, micromhos	25	50
Plate resistance, ohms	40,000	1,000,000
Grid current, amperes	10^{-15}	10^{-12}
V_1 in Fig. 4, volts.	−4	−1.5
V_2 in Fig. 4, volts.	2.5	4
V_3 in Fig. 4, volts.	4	6
V_4 in Fig. 4, volts.	6	22.5

are vacuum-tube electrometers. The sensitivities shown in the table are chosen to be *representative only*. They are not the ultimate sensitivities obtainable, but are those at which it is convenient to use the respective instruments. The electroscopes are all well known types and need not be further commented upon. The characteristics of the electrometer vacuum tubes are listed in Table II. They are assumed to be connected in the simple circuit indicated in Fig. 4. It may easily be shown that the sensitivity of a vacuum tube with galvanometer used in this manner is given by the relation:

$$\frac{dx}{dE} = \frac{gT}{1 + R_g(1/R_p + 1/R_L)}, \qquad (4)$$

where g is the mutual conductance of the vacuum tube in amperes per volt, T the galvanometer sensitivity in divisions per ampere, R_g the galvanometer resistance, R_p the plate resistance of the vacuum tube, and R_L the load resistance indicated in Fig. 4. Since R_p and R_L are generally large compared with R_g, the voltage sensitivity is only a little less than gT. The resistance R_L is best adjusted to have the galvanom-

FIG. 4.



Circuit diagram of a vacuum tube electrometer.

eter critically damped. Other vacuum tubes, besides those mentioned in Table II, are suitable also to use as electrometer tubes. The Western Electric Company's number D-96475 tube is quite similar to the FP54, and many types of ordinary radio tubes occasionally have grid impedances high enough for these purposes; for example, types 89 and 954 have been very successfully used.

LIMITS OF SENSITIVITY OF IONIZATION MEASUREMENTS.

Let us choose for an example an ionization chamber in the form of a cylinder 10 cm. long and 10 cm. in diameter, so that the mean path length of a ray through the chamber may be taken as 10 centimeters. The chamber will have a volume of 785 cc. and an internal surface area of 471 cm^2. Let us take the capacity of the electrode system, including the measuring instrument, to be 10^{-11} farads, and let the resistance between

the electrode and the guard ring be 10^{12} ohms. This gives us a time constant of ten seconds, which means that we shall have to wait, say, about 30 seconds to let the electrode potential come to equilibrium. The last column of Table I gives the numbers of scale divisions, respectively, corresponding to an ionization current of one million ion pairs per second formed in the chamber when it is used in conjunction with each of the measuring instruments. The values for the RCA 38 electrometer tube are calculated on the assumption that the resistance is only 10^{11} ohms instead of 10^{12} ohms, since the grid resistance of the tube is itself only 10^{12} ohms. This shortens the time constant to one second for this case.

MEASUREMENT OF ALPHA RAYS.

Let us suppose that we have a source of alpha rays in our chamber at atmospheric pressure, and let us suppose that each alpha particle will produce 10^5 ion pairs, which is the order of the number of ion pairs produced by the alpha particles from the natural radioactive substances. We can then compute the values (given in Table III) for the number of par-

TABLE III.

Sensitivities of Chambers for Alpha and Beta Particles.

No.	Instrument.	Alpha particles per second per division.	Divisions per alpha particle.	Limit of number of beta particles per second detectable.†
1	Gold leaf electroscope	600		2500
2	Double fiber electroscope	200		830
3	Single fiber electroscope	2		8.3
4	Lindemann electrometer	0.6	0.16	2.5
5	Quadrant electrometer	0.06	(1.6)	0.3*
6	FP54 & 300 megohm galvanometer	0.025	4.0	0.3*
7	FP54 & 10^4 megohm galvanometer	0.0007	(132)	0.3*
8	RCA 38 & 300 megohm galvanometer	0.12	8	0.9*

* Limit imposed by fluctuations; see text.
† Chamber filled with 25 atmospheres of argon.

ticles per second which will give us a deflection of one scale division, for each of the various instruments. We see that we need less than one alpha particle per second for one scale division in all except the first three cases. This means, of

course, that no steady deflection will be reached but that the effects of the individual alpha particles will be detected. The sensitivities are thus too high for a measurement of alpha particle current, and we should naturally resort to counting the individual alpha particles. If the alpha particles are to be clearly separated, there are three necessary conditions to be fulfilled:

1. The interval between successive alpha particles must be long compared to the period of the instrument.
2. The period of the instrument must be short compared to the time constant, RC, of the chamber.
3. The time necessary to collect the ions must be short compared to the period of the instrument.

Condition 3 can be satisfied in all cases provided a sufficiently high potential is applied across the ionization chamber. The time required for an ion to travel across the chamber may be calculated in an obvious manner from the field and the mobility. Unless very weak alpha activity is to be measured, condition 1 imposes quite serious limitations. These may be somewhat lessened by shortening the time constant of the electrode system and employing some amplification after the electrometer tube. Common usage terms such an appliance a "linear amplifier." Space forbids our entering into a discussion of these instruments. Condition 2 rules out some of the instruments that we are considering here; the quadrant electrometer, (5), and the FP54 used with a 10^4 megohm galvanometer, (7), are both too slow in response to be suitable. A Lindemann electrometer, (4), is somewhat insensitive, but either of the vacuum-tube electrometers when used with a short period galvanometer are eminently suited to count the individual particles.

The smallest number of particles that can be counted depends upon the radioactive contamination of the chamber itself. No substance that we can obtain is completely free from this contamination, and the amount of it varies over quite wide ranges. Radioactive contamination on metals arises from three sources: (1) contamination from radioactive substances which are distributed throughout the metal as a small impurity, (2) radioactive material, chiefly radium A,

which is deposited from the radon in the atmosphere, and (3) surface contamination from other sources. Contamination from this third source may be reduced by cleaning the surface with an abrasive or by copper-plating it, using very pure solutions. The number of alpha particles produced by the deposition of radioactive material from the air is easily estimated. When an atom of radon in the atmosphere disintegrates and becomes radium A, it also becomes ionized and will be attracted to any charged body in its vicinity and deposited upon it. The charged body will thus collect radioactive material until an equilibrium is reached, and the rate of collection becomes equal to the rate of decay of the material. The body, of course, need not have a potential different from that of the earth, since the conductivity of the atmosphere and the electric field at the surface of the earth will cause it to become charged and so to attract radioactive ions. Let us consider a sphere of 10 cm. radius, charged to such an extent that its potential in free space would be 100 volts. After equilibrium is attained, there will be emitted from the surface of the sphere a number of alpha particles of the order of 10^{-2} per square centimeter per second, if we have one atom of radon present per cubic centimeter of air. If the sphere is now removed from contact with the atmosphere, the contamination will decay almost with the period of radium B, and will amount to only 3 per cent. of its initial value in two and a half hours. After a sufficiently long time all of the contamination will have decayed to the long-lived substance radium D and will then emit only about 10^{-9} alpha particles per square centimeter per second. The alpha particle activity caused by the radioactive impurities in the metal itself is not so easy to estimate. We might quote a representative value observed for the activity of this contamination as 10^{-4} alpha particles per square centimeter per second. Thus in the case of the ionization chamber which we are considering, we should have five contamination alpha particles in every hundred seconds, and this may be taken as limiting the sensitivity. It is not the ultimate limit, to be sure, since by performing the experiment over a very long period of time we can measure the contamination to any desired degree of accuracy and likewise the additional number of alpha particles emitted by the source. The sensitivity

limit, which is indicated arbitrarily above, however, can be used in an obvious way to determine just how long an experiment would have to proceed in order for the number of alpha particles present to be counted with any given degree of precision, and therefore represents a practical quantity.

IONIZATION BY BETA PARTICLES.

We can proceed in an exactly similar manner to determine the deflection that would be produced by a given number of beta particles crossing the chamber per second, and we can define our limits of sensitivity in a practical manner as follows. The smallest number of beta particles that we can detect is defined as either (1) equal to the number of beta particles per second which will give a one-division deflection, or (2), equal to the number of particles which will produce a deflection which is as great as the standard deviation of the deflection produced by the background ionization. Now, the unavoidable contamination of alpha particles will contribute immensely to the fluctuations in the background of the chamber, but we can suppress this by using the chamber at a high pressure where the alpha particle ionization is reduced by recombination, while the ionization of beta particles is increased as long as we do not use so high a pressure that the ranges of the particles become smaller than their path in the vessel. If the effects of individual alpha particles are recognizable in the deflections of the measuring instrument, it is possible to subtract these effects directly, and the use of a high pressure in the chamber can be avoided. The other important factors which contribute to the background in a chamber of the dimensions here considered, are the natural radioactivity of the surroundings, and the cosmic radiation. Both of these produce their effects by means of high energy electrons, and these effects, and the fluctuations in these effects, are increased with increasing pressure in the same way as the beta ray ionization is increased. Thus we do not gain, when we are using a sensitive instrument, by increasing the pressure except by the suppression of the alpha particle effects. Let us, therefore, suppose that we have our chamber filled with argon at a pressure of 25 atmospheres and a sufficiently high field is employed to have the saturation for beta particles practically 100 per cent.

This will increase the cosmic-ray and the beta- and gamma-ray effects by a factor of 25, while reducing the alpha particle effects by a factor of about 3. Let us assume that the beta particles which we measure have a specific ionization of 100 ion pairs per centimeter in argon at atmospheric pressure, so that each beta particle will produce 25,000 ion pairs in the chamber at high pressure. In the last column of Table III are given the smallest numbers of beta particles per second that we can detect. The numbers which are without stars are the numbers of beta particles, per second, which produce a one-division deflection. The starred numbers (*) are the numbers of beta particles which give a deflection equal to the mean fluctuation in the chamber background. We shall now proceed to show how these latter numbers are obtained.

We must first define the standard deviation of a deflection. Suppose we have a spot of light moving across a scale. Its position varies in an irregular way with time. We make a large number of observations of the position of the spot. We find the mean position, and compute the square root of the mean of the squares of the deviations of the observed positions from the mean position. We then repeat this a large number of times. The average of the root mean square deviations is called the standard deviation. It is independent of the number of observations, and of the time interval between the observations if we have repeated the process sufficiently often. We shall now state without proof that if we have a system which has a recovery time T (in exactly the same sense as RC is the recovery time of our electrical circuit), which is long compared to the period of the instrument used for observation, and if that system receives on the average N particles in that time T, and if the deflection produced by one particle is a, then the standard deviation of the spot from its mean position is $a\sqrt{N}$. It is to be noticed that this statement is *not* equivalent to saying that the standard deviation of a Poisson distribution is the square root of the expected number of events. We can easily compute that, crossing our particular chamber (since 1.5 cosmic rays pass through a sphere of one square centimeter cross-section per minute) there are 3.2 cosmic rays per second, or 32 cosmic rays within the recovery time. Since a cosmic ray, because of its higher energy, will produce only

about half as much ionization as the beta rays which we were considering, the standard deviation in the position of the spot of our measuring instrument corresponds to three-tenths of a beta ray per second. In calculating this figure, we have assumed that the cosmic rays arrive at the chamber individually at random. This is not strictly true, since there occur showers or groups of cosmic rays passing through the chamber simultaneously. The result of this will be to increase the value of the standard deviation somewhat, but not by more than 30 per cent., the exact value depending very much upon the geometrical arrangement of the apparatus. This departure from randomness therefore will not affect appreciably our calculation of the limits of sensitivity if we disregard it entirely. We have also neglected any consideration of the fluctuations in the gamma-ray background. These are in general of the same order of magnitude as the cosmic-ray fluctuations. They vary greatly, however, from one experimental arrangement to the next, and it is not possible to make any definite statements about them. At any rate it is possible to eliminate them entirely by surrounding the chamber with lead shields.

The calculation of cosmic-ray fluctuations may be put into a more concise form. Let A be the chamber area, and n the number of cosmic rays per square centimeter per second. Then the number of cosmic rays passing through the chamber in the time RC is

$$N = nARC.$$

If l is the mean path through the chamber, p the pressure of the gas, J_e the mean specific ionization of the cosmic-ray particles, and S the sensitivity of the recording instrument in divisions per volt, then a, the deflection produced by one particle, is given by

$$a = SeJ_e lp/C. \tag{5}$$

The standard deviation of the spot from its mean position is

$$F_e = a(nARC)^{\frac{1}{2}},$$

or

$$F_e = SeJ_e lp\left(\frac{nAR}{C}\right)^{\frac{1}{2}}. \tag{6}$$

Since each cosmic ray does not have the same length of path in the chamber, to be strictly accurate we should calculate the fluctuations separately for the rays of each path length and then combine them by taking the square root of the sum of the squares of the separate contributions. The result of this more accurate calculation would differ from the expression given above only by a factor of the order of unity, and we shall disregard it. If J_β is the specific ionization of a beta particle, an ionization current produced by one beta particle per second results in a deflection of $SeJ_\beta lpR$ divisions. The standard deviation of the deflection expressed in terms of beta particles per second is then

$$F_c' = \frac{J_c}{J_\beta}\left(\frac{nA}{RC}\right)^{\frac{1}{2}} \text{ beta particles per second.} \qquad (7)$$

As above, for our chamber we have $J_c/J_\beta = \frac{1}{2}$, $nA = 3.2$ per second, $RC = 10$ sec., and hence $F_c' = 0.3$ per second.

The background ionization will have, in addition, other irregularities varying from day to day and depending upon the barometric pressure, the temperature, and other meterorological factors. Representative values of the background and its daily fluctuations are given in Table IV. It will be noticed

TABLE IV.

Representative Values of the Residual Ionization and its Day to Day Fluctuations.
Values in ion pairs per cc. per second.

Pressure	1 atmosphere.	25 atmospheres.	
Gas	N_2 or A.	N_2.	A.
Per cent. saturation for field of 100 volts/cm.	100%	58%	100%
Cosmic-ray ionization	2 ± 0.2	30 ± 3	50 ± 5
Alpha-ray ionization	10 ± 0	1 ± 0	3 ± 0
Beta- and gamma-ray ionization	4 ± 1	58 ± 15	100 ± 25
Total	16 ± 1	89 ± 15	153 ± 25

that although the percentage fluctuations in each contribution to the total ionization is independent of the pressure and the gas in the ionization chamber, the percentage fluctuation in the total ionization does depend upon them.

Table V gives the deflections of the various instruments

TABLE V.

Deflections Produced by the Residual Ionization in the Chamber under Consideration.

Instrument.	Background.	Statistical fluctuations in the background.	Day-to-day fluctuations in the background.
1	0.002	0.00012	0.0003
2	0.006	0.00036	0.0009
3	0.6	0.036	0.1
4	1.9	0.12	0.3
5	19	1.3	3.0
6	48	3.0	8.0
7	1600	100	270
8	9.6	1.8	1.6

produced by the residual ionization in our chamber, as well as the fluctuations in these values.

IONIZATION BY GAMMA RAYS.

Gamma rays, in contrast to alpha and beta particles, do not produce ionization directly, but only through the agency of the secondary electrons which they produce. In the energy range of usual interest, i.e. from one-half million to ten million volts, these secondary electrons are produced by three processes: by the photoelectric effect, by Compton collisions and by pair production. If we wish to know how many gamma rays can be detected in an ionization chamber, we must know the number of secondary electrons per gamma ray at each point in the path of the gamma-ray beam. The accurate calculation of this would be laborious, and we shall rely upon an approximation which is sufficiently accurate for the present purposes. Let us suppose that all of the energy of each gamma ray which is lost by absorption appears in an electron traveling in the direction of the original gamma ray and having all its energy. Thus if we have a beam of n photons, there will be μn photons lost per unit of path, where μ is the asbsorption coefficient for the radiation. The number of electrons appearing will also be μn per unit path, and the number of electrons after the beam has reached equilibrium will be μnR, where R is the range of an electron of the energy of the gamma ray. This approximation is a good one even in the case of pair production as long as the range is proportional

to the energy, since even though two electrons are produced, they will only travel, on the average, half as far. The maximum error is in neglecting the rest masses of the electron pair. The value of μR depends, of course, on the substance through which the gamma rays are passing, and its change as we go from one substance to another is the well known transition effect.

Let us now assume that the walls of our ionization chamber have a thickness equal to R so that we may neglect the transition from the air to the chamber walls. Moreover if the path in the ionization chamber is small compared to the range of the ejected electrons in the gas, we may neglect the second transition from the walls to the interior of the chamber. In Table VI are given values of μ/ρ, that is, the absorption coefficient

TABLE VI.

Absorption Coefficients of Gamma Rays and Ranges of High Energy Electrons

Energy volts.	Absorption coefficient, μ/ρ cm²./g.			Range $R\rho$ in g./cm².		μR.	
	Al.	Cu.	Pb.	Al.	Pb.	Al.	Pb.
5×10^5	0.082	0.084	0.121	0.17	0.34	0.014	0.041
10^6	0.059	0.057	0.060	0.40	0.80	0.024	0.048
2×10^6	0.041	0.040	0.041	0.89	1.8	0.036	0.074
5×10^6	0.029	0.034	0.043	2.4	4.7	0.068	0.20
10^7	0.024	0.033	0.055	5.	10.	0.12	0.33

in units of cm²./gram, and the ranges of electrons for several values of the energy. These values are theoretical ones and are only approximate. Although there is no reason to doubt the correctness of the theoretical values of these quantities, it is well to note that there are very few experimental data in this energy range.

Since we know the number of electrons which accompany a gamma-ray beam, we can compute the smallest detectable number of gamma rays that we can observe with our various instruments. We define this number of gamma rays exactly as we did for beta particles, namely, for instruments of small sensitivity the limiting number of gamma rays per second is equal to the number which produce a deflection of one division, if the statistical fluctuations are less than this amount, or, if

the statistical fluctuations are appreciable, as with instruments of high sensitivity, we define the limiting number of gamma rays detectable as equal to that which will produce a deflection equal to the standard deviation of the fluctuations. We have assumed in all cases that the range of the beta particle is greater than the dimensions of the chamber. This will not be strictly true of the gamma rays of lowest energy but, since we are interested only in orders of magnitude, a more correct calculation is not deemed worth while. Our approximation that the specific ionization is independent of the energy is, of course, subject to the same criticism. Table VII gives the

TABLE VII.

The Smallest Detectable Number of Gamma Rays per Second.

Instrument \ Energy, volts	5×10^5.	10^6.	2×10^6.	5×10^6.
1 Gold leaf electroscope	167,000	104,000	69,000	37,000
2 Double fiber electroscope	55,000	35,000	23,000	12,000
3 Single fiber electroscope	550	350	230	122
4 Lindemann electrometer	167	104	69	37
5 Quadrant electrometer	20*	13*	8*	4.5*
6 FP54 & 300 megohm galvanometer	20*	13*	8*	4.5*
7 FP 54 & 10^4 megohm galvanometer	20*	13*	8*	4.5*
8 RCA 38 & 300 megohm galvanometer	60*	36*	25*	13.*

* Limit imposed by fluctuations: see text.

results of these calculations for our chamber filled with 25 atmospheres of argon.

RELATIVE SENSITIVITY OF GEIGER COUNTERS AND IONIZATION CHAMBERS.

It might be supposed from a cursory examination that, since Geiger counters are able easily to record individual beta particles, they are intrinsically more sensitive than ionization chambers. However, a second glance is sufficient to convince one that this is not so. For, with either a counter or a sensitive ionization chamber, it is the cosmic-ray fluctuations which are most powerful in determining the limit of useful sensitivity, and these effects are the same for both counters and ionization chambers of the same size and shape. Thus the decision as to whether a counter or an ionization chamber is more suitable for a given purpose depends on quite other factors than the sensitivity. The same argument is valid for the measurement

of gamma radiation, since the efficiency of detection of gamma rays by a counter is just equal to that for an ionization chamber, and is the value of μR which we have quoted above, as long as μR is small compared to unity.

THE LIMITS OF MEASUREMENT FOR VERY SMALL IONIZATION CHAMBERS.

We have seen above that the fluctuations in the cosmic radiation form the essential limitation on the number of beta or gamma rays that can be detected in the ionization chamber of the size we have considered. Moreover, this limitation is independent of the size of the chamber, since the ionization effects of the cosmic rays and the particles to be measured are changed in the same way, as the size of the chamber is changed. If, however, we reduce the chamber to very small dimensions or if the pressure is not high, two new types of fluctuations besides those caused by the cosmic radiation become important.

The first type of fluctuation occurs in vacuum tube electrometers and is caused by the finiteness of the elementary charges flowing to the grid of the vacuum tube. In a vacuum tube both electrons and positive ions formed from the residual gas are present to some extent, and the current flowing to the grid is the difference in the number of positive ions and electrons received by the grid per second. Although the average number of ions or electrons received per second may remain constant, there will be fluctuations from this average, and these fluctuations in the current will cause random variations in the potential of the grid of the vacuum tube. This phenomenon is called the shot effect. If i_g is the sum of the absolute values of the averages of the positive ion and electron currents, the standard deviation in the potential of the grid is given by

$$E_s = \left(\frac{e i_g R}{2C}\right)^{\frac{1}{2}}, \tag{8}$$

where e is the elementary charge, R and C the resistance and capacity of the grid respectively. For a type FP54 tube, using the value of i_g given in Table II, and R and C as in the example of the ionization chamber considered above, the shot voltage E_s, may be calculated to be 2.8×10^{-6} volts. For the type 38 tube, used under the conditions considered above, E_s is equal to 2.8×10^{-5} volts. There will also be fluctuations

caused by the shot effect in the plate current of the vacuum tube. The magnitude of these fluctuations is generally negligible, however, compared to the fluctuations caused by the grid current.

The second type of fluctuation is present in both vacuum tubes and in electroscopes, and is caused by the thermal motions of the electrons. These fluctuations are customarily called the Johnson effect. For the simple type of circuit which we are here considering, that is, a resistance in parallel with a capacity, the root mean square potential fluctuation is given by

$$E_j = \left(\frac{kT}{C}\right)^{\frac{1}{2}}, \tag{9}$$

where k is Boltzman's constant and is equal to 1.37×10^{-16} ergs per degree, and T is the absolute temperature. For a capacity of 10^{-11} farads as we have assumed above, E_j is 2×10^{-5} volts.

In addition to the shot and the Johnson effects, vacuum tubes will sometimes have intrinsic voltages fluctuations or noise which are presumably caused by changes in the emission properties of the cathode surface. The magnitude of the effect depends greatly on the individual tube in consideration and may be larger than either of the two effects considered above. By proper selection, however, it is possible to find tubes in which the noise from this source is small. The total fluctuation of potential is obtained by taking the square root of the sum of the squares of the standard deviations of the fluctuations from each source, since the separate fluctuations are independent of each other. We may write the total voltage fluctuation for the tube or electrometer as

$$E = \left[\frac{ei_gR}{2C} + \frac{kT}{C} + E_n^2\right]^{\frac{1}{2}}, \tag{10}$$

where E_n is the contribution of the tube noise. The fluctuation in terms of divisions of deflection is ES. If we include the fluctuations from the cosmic radiation as given by equation (6), the total fluctuation may be written as

$$F = S\left[e^2J_c^2l^2p^2\frac{nAR}{C} + \frac{ei_gR}{2C} + \frac{kT}{C} + E_n^2\right]^{\frac{1}{2}} \text{ divisions}, \tag{11}$$

or in terms of the number of beta particles per second

$$F' = \left[(J_c/J_\beta)^2 \frac{nA}{RC} + \frac{i_0}{2eJ_\beta^2 l^2 p^2 RC} + \frac{kT}{e^2 J_\beta^2 l^2 p^2 R^2 C} + \left(\frac{E_n}{eJ_\beta lpR} \right)^2 \right]^{\frac{1}{2}}. \quad (12)$$

We can easily see that if the size of the chamber is reduced, that is if l and A are made smaller, the cosmic ray fluctuations become less important and the electrical noises become more important until they exceed those caused by the cosmic rays.

With a knowledge of the electrical fluctuations it becomes possible to design an apparatus capable of detecting an individual cosmic ray or beta particle, and indeed such measurements have been made to determine the specific ionization of the cosmic ray particles. The problem is quite analogous to that of counting alpha particles except that each particle produces a smaller number of ion pairs. The smallest potential that can be measured is $(kT/C)^{\frac{1}{2}}$ regardless of the instrument used, and this degree of sensitivity is by no means difficult to attain.

In conclusion, we wish to thank Dr. W. F. G. Swann for his helpful suggestions on many points, particularly with regard to the best method of presentation of this material.

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Many important points in connection with the use of ionization chambers have been omitted from the above discussion, while others have received only scant attention. It is hoped that the following bibliography will supplement the text and, to a large extent, provide the means to remedy these deficiencies.

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No Substitutes Oust Wood As Tie Material.—More than 2,500 patents have been granted in the last 50 years for railroad tie materials other than wood, says the booklet, Products of American Forests, issued by the United States Department of Agriculture. But in general, railway traffic continues to move on a wood foundation. J. Alfred Hall and T. J. Mosley, of the Forest Products Laboratory, estimate that about a billion wooden ties are in service. There is an annual renewal of about 100 ties to the mile, on the average, but several important railroads get along with yearly renewals of 50 to 75 ties a mile. This longer life of the tie results from better roadbed, better construction methods, and chemical treatments with preservatives. In recent years railroads have been buying about 50,000,000 ties a year, compared with nearly 150,000,000 thirty years ago. Three-quarters of the ties are now treated before they are laid. Cheapness, strength, elasticity, resistance to shock, ease of replacement, and electric insulating properties are qualities of wood ties that account for the demand that promises a continuing market for this staple product of American woodlands.

R. H. O.

Iron Reworked in Body.—The human body, like industry, uses iron over and over again, says an article by Miss MABEL A. DICKSON in the current Yearbook of Agriculture. Although the body contains only a little more iron than there is in a shingle nail, it is essential in the red coloring matter of the blood to make the blood an effective carrier of the oxygen the body requires in its chemical service to the living cells. These blood cells break down, but not much of the iron is wasted. About 85 per cent., Miss Dickson explains, is salvaged and goes finally to what corresponds to a factory—the bone marrow— for the formation of new red cells. So effective is this process of iron conversion and reuse that an average adult male needs to absorb daily from his food only about one-sixth as much iron as the body requires in one day to make red blood cells. The body is able to store a moderate reserve of iron, but a fairly regular and adequate intake of iron is essential to continued good health. Another article in the yearbook lists more than 30 excellent sources of iron and a score of good sources. These include most of the green-colored vegetables, lean meats, poultry, eggs, oysters and shrimps, several dried fruits, whole ground cereals, molasses, legume seeds, and liver, heart, and kidneys.

R. H. O.

THE ACCELERATED FLOW METHOD FOR RAPID REACTIONS.

BY

BRITTON CHANCE.

PART I. ANALYSIS.

(Continued from April issue.)

2. The Linear Dimensions of the Observation System.

A. The Distance from the Point of Mixing to the Point of Observation.

The distance from the mixing chamber to the point of observation, $\frac{s_1 + s_2}{2}$, should be small to permit the measurement of short times. If this distance is made very small the reactants will not be completely mixed before reaching the observation point. Hartridge and Roughton [1] and Millikan [2] have made extensive tests on mixing. It is felt justifiable to apply Millikan's [2] results on mixing to the mixers used here as both types had four 0.5 mm. tangential jets. If these results are plotted against distance from the point of mixing to the point of observation, it is seen that the point, 98 per cent. mixed, moves towards the mixing chamber as the flow velocity is increased. This is exceedingly satisfying since such a relation would indicate that mixing improves as the flow velocity increases.

Hence for a given value of $\frac{s_1 + s_2}{2}$, the mixing should be complete at high flow velocities if it is complete at low flow velocities.

The type of mixing test employed for this apparatus is very simple and only qualitative. The reaction of iodine and thiosulfate is very rapid and its rate is affected by the concentration of both reactants. The extent of reaction is measured for a wide range of concentration and flow velocities and is found to be complete. If the mixing were at fault, the reaction would remain incomplete over a rather wide range of concentrations and such incompleteness is not observed.

B. The Bore of the Observation Tube.

The bore of the observation tube, d_0, has been shown to have little affect on the value of K^1, under the conditions where d_0 is chosen with due regard to L, the length of the observation tube. This means that for a given pressure the flow velocity attainable is not affected by d_0. If, however, the pressure available for discharging the reactants is not limited, the time range of the apparatus increases as the square of d_0, cf. (1). As d_0 becomes quite small the width of the light beam passing through the observation tube must also be small and the apparatus is quite similar to devices built for the express purpose of measuring minute displacements of the observation tube relative to the light beam. As d_0 becomes small the driving forces, hence the stress on the mechanical parts, becomes greater. For these reasons, the limits to d_0 are set by the mechanical rigidity of the supports for the observation tube and the lens system. For a given value of d_0, it has been shown that the range of the apparatus can be increased by increasing, W, the width of the light beam passing through the observation tube. There is, therefore, interaction between the choice of the slit width for maximum range and for minimum disturbance due to mechanical vibration. In this case the apparatus is made of a single bronze casting and a beam of light 0.2 mm. wide is passed through the center of a 1 mm. bore observation tube.

C. The Slit Length.

The slit length, $s_2 - s_1$, is defined as the length along the observation tube from which light reaches the photoelectric cell. It is of considerable importance in determining the range of the apparatus as it appears in both (14) and (21). It has been stated that the slit length is limited by an error that it causes in the measurement of non-linear kinetic curves. The photocell integrates the light it receives from the different parts of the observation tube. The distance from the point of mixing to the point of observation is calculated by taking the arithmetic mean of s_1 and s_2. The integrated value will be different from the arithmetic mean to an extent depending upon the non-linearity of the kinetic curve at any particular point and the ratio of the slit length to the arithmetic mean distance from the point of mixing to the point of observation.

The Slit Length Error for a Monomolecular Reaction.

The extent of a monomolecular reaction may be expressed:

$$\frac{c}{c_0} = e^{-k_1 t}, \tag{34}$$

where c_0 is the initial concentration of the disappearing substance, c is its concentration at time t, k_1 is the monomolecular velocity constant, and t is the time after mixing the reactants.

The photocell measures $\bar{c}_1$ the integrated average of c. Hence,

$$\bar{c} = \frac{c_0}{t_2 - t_1}\int_{t_1}^{t_2} e^{-k_1 t}dt = \frac{-c_0}{k_1}\frac{(e^{-k_1 t_2} - e^{-k_1 t_1})}{(t_2 - t_1)}, \tag{35}$$

where

$$t_2 = \frac{s_2}{u_0}, \qquad t_1 = \frac{s_1}{u_0}, \tag{36}$$

u_0 is the linear flow velocity.

The value of c corresponding to the arithmetical average is

$$\underline{c} = c_0 e^{-k[(t_2+t_1)/2]}. \tag{37}$$

The error due to slit length is defined as

$$e = \frac{\bar{c} - \underline{c}}{\underline{c}} \times 100. \tag{38}$$

The error is zero when the integrated value is equal to the arithmetical mean value. The error is also taken as a percentage of the measured quantity, not as a fraction of c_0 the initial quantity.

By substituting (35) and (37) in (38) we obtain

$$e = 100.\frac{2}{k_1(t_2 - t_1)} \cdot \sinh k_1 \frac{(t_2 - t_1)}{2} - 1, \tag{39}$$

but

$$k_1 = \left[-\log e \frac{c}{c_0} \right] \frac{2u_0}{s_1 + s_2} \tag{40}$$

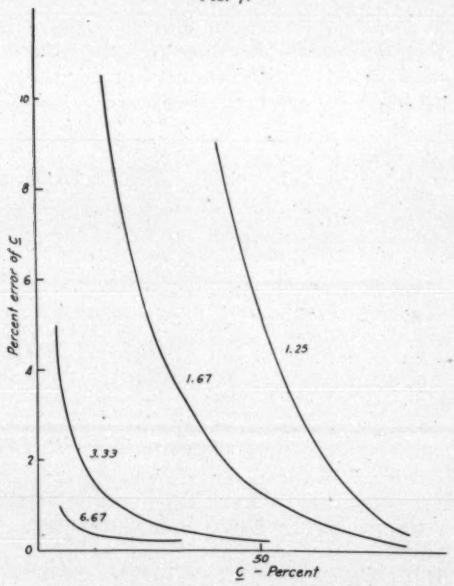
from (2) and (34).

By substituting (36) and (40) in (39) it follows that

$$e = \frac{s_1 + s_2}{s_2 - s_1 \log e \frac{c}{c_0}} \cdot \sinh \frac{s_2 - s_1}{s_1 + s_2} \log e \frac{c}{c_0} - 1. \tag{41}$$

The slit length error depends upon the ratio of $\frac{s_1 + s_2}{s_2 - s_1}$ and the extent of reaction, as shown in Fig. 7.

FIG. 7.



The slit length error for values of $\frac{s_1 + s_2}{s_2 - s_1}$.

The sign of the error is such that $\bar{c}$, the value measured by the photoelectric system, is greater than c, the value obtained if there were no slit length error.

A value of 3.33 is taken as a conservative value for the ratio $\frac{s_1 + s_2}{s_2 - s_1}$ and is used in this apparatus. The maximum error is only 0.2 per cent. of c_0. If, however, it is desirable to increase the range of the apparatus by decreasing $\frac{s_1 + s_2}{s_2 - s_1}$ further, the relations stated will give the error.

1 is considered a reasonable limit to the ratio $\frac{s_1 + s_2}{s_2 - s_1}$ as the maximum error is 12 per cent. of c_0.

Similar analysis has been applied to the slit length error of a bimolecular reaction and it is found that the error is somewhat less than that for a monomolecular reaction. It should be kept in mind that the curvature of the kinetic curve is the important factor and a calculation of slit length error should be made if a highly inflected kinetic curve is obtained experimentally.

3. The Accelerated Flow Method.

The accelerated flow method differs from previous methods as observations of the extent of reaction can be made when the flow velocity is not constant. This feature permits the use of continuous recording and the attainment of high fluid economy. The fundamental equation for any flow method is

$$t = \frac{s_1 + s_2}{2u_0}. \qquad (1)$$

If continuous recording is desired, t must be varied. While it would be possible to vary $\frac{s_1 + s_2}{2}$, optical, mechanical, and electrical complexities make this difficult.* u_0 is therefore varied so that t will vary over the desired range and values of u_0 are continuously recorded against simultaneous values of the extent of reaction.

It has been stated that a, the acceleration of the flow, is limited by an error introduced into the measurement of t since the flow is no longer constant over the interval t. Taking V_1 as the flow at t^1, the time of measuring the extent of reaction, it follows from (22) and (1)

$$t_m = \frac{s_1 + s_2}{2} \cdot \frac{\pi d_0^2}{4at^1}, \qquad (42)$$

where t_m is the value of time calculated from the experimentally measured value of flow velocity.

* Stern and Dubois have constructed such an apparatus, details of which are soon to be published.

The actual value of flow during the true time, t, required for the reactants to move from mixing to observation is

$$a(t^1 - t/2), \tag{43}$$

whence

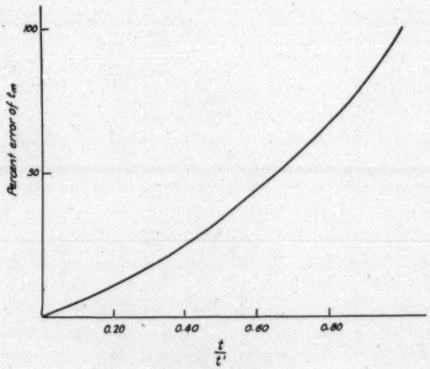
$$t = \frac{s_1 + s_2}{2} \cdot \frac{\pi d_0^2}{4a(t^1 - t/2)}, \tag{44}$$

the error of the measured value, t_m, is defined

$$e = \frac{t - t_m}{t_m} \times 100 = \left[\frac{1}{1 - \frac{t}{2t_1}} - 1 \right] 100. \tag{45}$$

This error is plotted in Fig. 8.

FIG. 8.



The acceleration error.

The largest value of the error under these conditions is 100 per cent. since t/t^1 cannot be greater than 1. The first particle of liquid to reach the point of observation, after $t^1 = 0$ does so in a time

$$\sqrt{2 \frac{A_0}{a} \frac{s_1 + s_2}{2}}. \tag{46}$$

Under these conditions $t = t^1$ and $t_m = \frac{t}{2}$.

In this case t_m is smaller than t since V_1 at t_m is greater than V_1 at t. If a, the acceleration of the flow were negative, t_m would be greater than t, since V_1 at t_m would be less than V_1 at t. It has been shown previously that $\bar{C}$, the extent of reaction measured by the photoelectric system is greater than C, the extent of reaction if the slit length error is absent. Therefore the slit length and acceleration error counteract each other when a is negative. For this reason the kinetic data obtained with negative acceleration has always been used in this method. This does not in any way affect the applicability of the analysis.

The acceleration error can be put in terms of the extent of a monomolecular reaction and the overall slit length and acceleration error can then be calculated. For simplicity

$$\bar{u} = \frac{u_0 + \sqrt{u_0^2 - 2as}}{2}, \tag{48}$$

$$s = \frac{s_1 + s_2}{2}, \tag{49}$$

$$u_0 = \frac{V_1}{A_0}, \tag{50}$$

$$u_0 = u_m - at, \tag{51}$$

where $\bar{u}$ is the mean flow velocity from mixing to observation.

c and c^1 are defined:

$$\frac{c}{c_0} = e^{-(k_1 s/u_0)}, \tag{52}$$

$$\frac{c^1}{c_0} = e^{-(k_1 s/\bar{u})}, \tag{53}$$

the error is defined

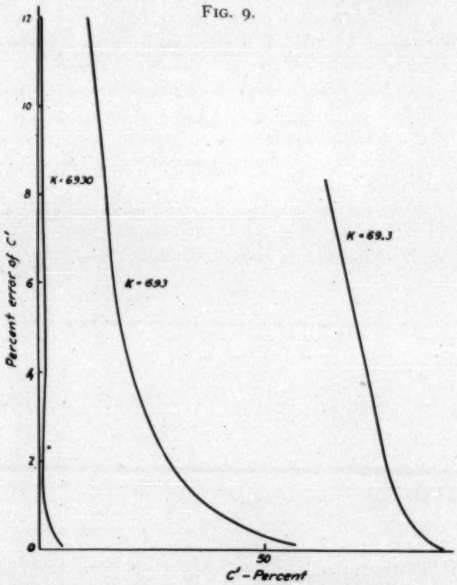
$$e = \frac{c^1 - c}{c} = \frac{e^{-(k_1 s/\bar{u})}}{e^{-(k_1 s/u_0)}} - 1. \tag{54}$$

By substitution and simplification

$$e = e^{-(k_1 s/u_0)} \left[\frac{\dfrac{u_0}{\sqrt{u_0^2 - 2as}} - 1}{\dfrac{u_0}{\sqrt{u_0^2 - 2as}} + 1} \right] - 1. \tag{55}$$

This expression is plotted in Fig. 9 for values of k_1 when $u_m = 20$ m./sec., $a = 100$ m./sec.^{2} and $s = 10$ mm.

FIG. 9.



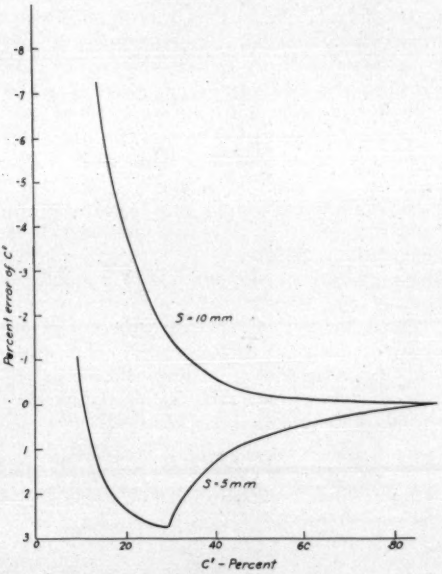
The acceleration error for various values of the monomolecular velocity constant when the maximum flow velocity is 20 m./sec., the acceleration of the flow is 100 m./sec^2. and the distance to the point of observation is 10 mm.

The total error of the method is the sum of the slit length and acceleration errors:

$$2\frac{s}{s_2 - s_1 \log_e \frac{c}{c_0}} \cdot \sinh \frac{s_2 - s_1}{2s} \log_e \frac{c}{c_0} + e^{\log_e (c/c_0)} \left[\frac{\frac{u_0}{\sqrt{u_0^2 - 2as}} - 1}{\frac{u_0}{\sqrt{u_0^2 - 2as}} - 1} \right] - 2. \quad (56)$$

This expression is calculated in Fig. 10 for

FIG. 10.



The total error due to slit length and acceleration error for a monomolecular velocity constant of 693, an acceleration 100 m./sec^2., a maximum flow velocity of 20 m./sec., a slit length of 3 mm., and distances from the point of mixing of 5 and 10 mm.

$$k_1 = 693$$
$$a = 100 \text{ m./sec}^2.$$
$$u_m = 20 \text{ m./sec.}$$
$$s = 10 \text{ mm. and } 5 \text{ mm.}$$
$$s_2 - s_1 = 3 \text{ mm.}$$

In the apparatus as developed the acceleration has been measured and found to be closely linear. Although it would be possible to apply these formulæ as a correction to the observed points, the stopped flow method is used for measuring times greater than 30 milliseconds while the accelerated flow

method is used for times from 10 to 0.2 milliseconds. If flow recording over a wider range is desired the acceleration may be suitably controlled by any of the methods to be discussed later. It can easily be shown that a mechanical drive operating according to a given law can eliminate the acceleration error. An example of this is a drive wherein the flow velocity is inversely proportional to time. In fact any device which decreases the acceleration when t/t^1 approaches unity would suffice. If it were desired to record in the time range where the error is large it would also be possible to alter the value of the acceleration. This present device has been designed primarily to study very rapid reactions with high fluid economy and it is felt that the error falls outside of the desirable range of the apparatus.

The time required for the particle of liquid to leave the mixing chamber and stop at the observation point is given by (46). The value of this expression for the present apparatus is approximately 30 milliseconds. Thus observations of the extent of reactions may be observed for values of time greater than 30 milliseconds directly as a function of time. This is the basis of the stopped flow method. Expression (46) shows that A_0 and $\frac{s_1 + s_2}{2}$ should be small and the acceleration should be large. The acceleration can be made very large by allowing the syringes to hit a stop although the microphonic tube noises are quite large when this is done.

4. The Photoelectric System.

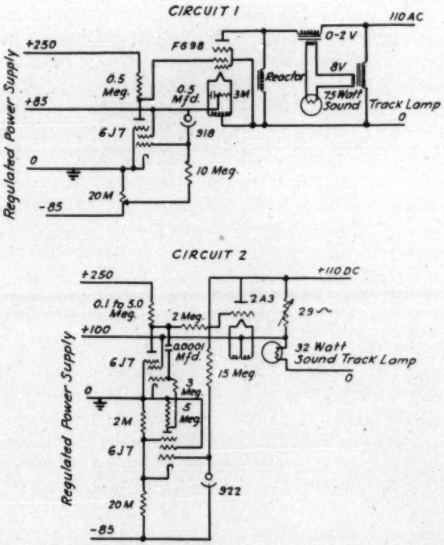
(a) Photoelectric Light Control.

The intensity of the light source, I_0, has been shown to be an important factor in all substance limited cases. It has been stated that I_0 is the intensity of the light source in the region where ϵ, the extinction coefficient of the reacting substance, is large. It is also desirable to isolate the region where ϵ is large. In this apparatus Chance or Corning filters have been used in conjunction with 32 or 75 watt tungsten filament sound track exciter lamps. These lamps are run at temperatures slightly in excess of the rated values.

Fluctuations in the intensity of the light source set a limit on the light intensity at which it is possible to attain the theoretical value of signal to noise ratio indicated by (12).

It has been found that light intensity rather than voltage stabilization of the light source is desirable. This is due to the relation between light intensity and applied voltage for an incandescent lamp. It has recently been pointed out by Mueller [10] that the light intensity may vary as the third or fourth power of the applied voltage. Chance [11] has given the general principles and basic circuits for photoelectric light control. These basic circuits are reproduced in Fig. 11.

FIG. 11.



Basic light control circuits. Circuit 1 uses a thyratron and is used to stabilize an A.C. light. Circuit 2 uses direct current and gives a "D.C." light. M = 1000 ohms.

Circuit 2 is favored for this application since it is necessary to measure rapid absorption change. The light intensity may not vary over the period of measurement even though this period be as short as 0.01 second. The present circuit is shown in Fig. 14. It differs from the previous circuits in that

it is attempted to make the overall operation of the light control and light measuring circuits differential towards voltage and circuit parameter variations. This is done by having approximately equal voltage drops across the photocell load resistors of each circuit. The amplifiers are of identical construction and gain. The control circuit does not require an impedance changer tube for the first stage as the value of its grid resistor is rather low. The resistors supplying potentials to both amplifiers are of identical ratings and value and are placed together to obtain identical thermal conditions. It has been found advisable to use a cupric chloride filter to avoid heating the cathode of the control photocell. These changes have decreased the rate of drift of the absorption measurement photometer to a great extent.

Theoretically the limit to the light stabilization should be set by the limits to amplification of the photocurrents. This should be a shot noise limited case as the available light intensity is large and expression (12a) applies for evaluating the shot noise. The signal to noise ratio will then be independent of the photocell load resistance if the drop across the resistance is greater than 1/20 volt. It has been found that oscillation of the light control circuit has limited the stabilization before the theoretical noise limit could be reached. This oscillation is probably due to the thermal inertia of the lamp filament. As this system is somewhat analogous to a servo mechanism it is possible that the utilization of time derivatives of the variation of light intensity for control purposes would stop the oscillation. In this circuit inverse feedback is provided to improve the frequency response of the amplifier and also to provide a gain control. The gain is increased to the point of oscillation of the present circuit. The ratio of input lumens to output lumens is 1 to 10,000.

The actual stabilization obtained depends entirely upon the variation of the supply voltage. This circuit has been operated from both storage batteries and D.C. supply mains.

(b) A Feedback Photometer.

The photocell sensitivity, S, has appeared as a fundamental variable in all the substance limited cases. S is defined as the photocell sensitivity in the region where ϵ is

large. There are available two types of photoemissive cells useful for photometry in the visible spectrum. They have rubidium and cæsium coated cathodes. The former is useful for absorption in the blue and green, while the latter is valuable in the red. The infra-red response of both types is considerable and care should be taken that the filter combinations used do not transmit in the infra-red. The vacuum photocell is preferred to the gas photocell because the latter is somewhat more noisy and equation (12a) does not hold for a gas-filled photocell.

The signal to noise ratio of the photoelectric system has also been shown to be a fundamental variable in substance limited cases. Expression (12) was used to calculate this value on the assumption that the signal voltage was less than 1/20 volt. This has been found to be the case in practise when luminescent reactions were measured and when the light was obtained from a narrow-slit monochromator or a dense filter system. If the light intensity and the signal voltage are large the following formula for the signal to noise ratio of a photocell with shot effect and a resistance with thermal agitation shows that the signal to noise ratio no longer depends upon R.

$$\frac{e^2_{\text{signal}}}{e^2_{\text{noise}}} = 1.59 \times 10^{18} \frac{(\Delta i)^2}{F} \cdot \frac{R}{iR + 0.0516}. \qquad (57)$$

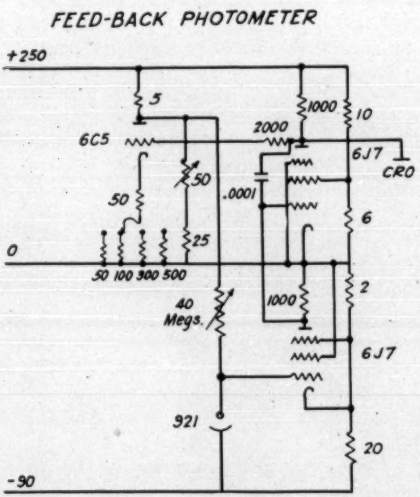
This formula is from Johnson and Llewellyn.[3]

Before these theoretical values of noise may be obtained there are many technical difficulties to be overcome. Especial attention must be paid to microphonic noise as the first tube is placed near the driving syringes and some of the vibration due to the rapid discharge of reactants is transmitted to this tube. The photocell is carefully shielded and the fluid in the observation tube must be at ground potential. It is also important to avoid leaks in the hydraulic system since a small amount of moisture causes large fluctuations in the photocell output.

Several makes of load resistance have been tested for noise and no significant difference was found under the conditions of the experiment. 100 megohms has been used for measurements of absorption in the blue and green while 10 megohms is satisfactory for measurements in the red.

The value of F is chosen with regard to its effect upon the signal to noise ratio and the fluid economy of the method. In the apparatus constructed using a manual drive with 1 cc. syringes a frequency response from zero to 20 cycles per second is the minimum requirement. A sharp cut off above this frequency is obtained by the use of by-passing in the amplifier and feed-back circuits.

FIG. 12.

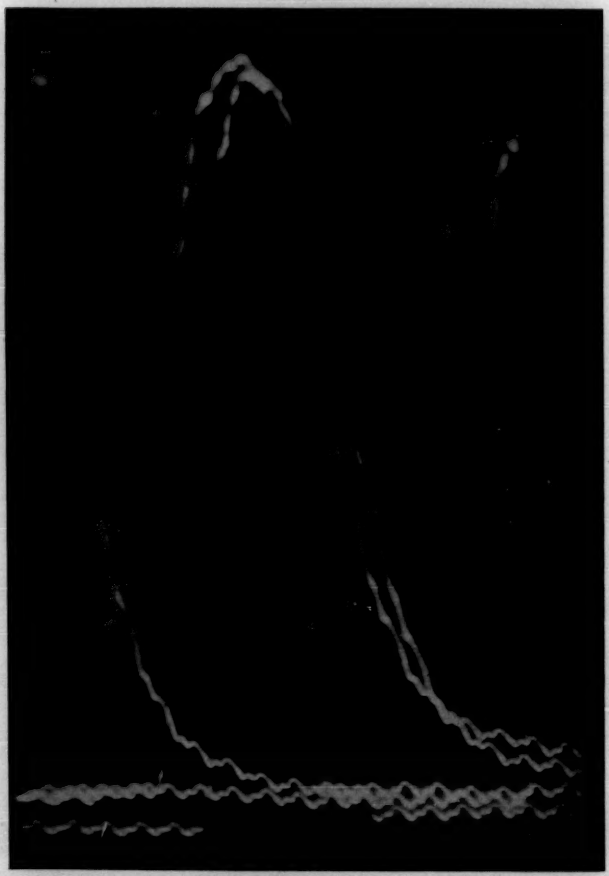


A feedback photometer having variable calibrated sensitivity and used for measuring small changes in white or red light. Resistance in thousands of ohms and capacitances in microfarads.

A variety of amplifiers have been constructed to obtain freedom from microphonics, grid currents, noise, and drifts. As it is necessary to measure the initial and final values of absorption of the reactants, direct coupled amplifiers were favored. It is also desirable to have constant and calibrated amplifier sensitivity over a wide range. This was accomplished by the use of inverse feedback. The basic circuit of a feedback photometer is shown in Fig. 12. The output

voltage from the amplifier is fed back directly to the grid of the first amplifier tube by a parallel feedback network. The feedback ratio was adjusted varying the cathode load, hence the gain of the 6C5 used for phase inversion of the feedback voltage. This circuit was satisfactory for measurement of absorption of white or red light. The final design of the amplifier is shown in Fig. 14. A 926 or 922 phototube is supplied with a potential of 320 volts and a load resistance, R, of 100 megohms. The potential applied to the photocell is varied by a "coarse" and "fine" potentiometer system to compensate for changes in light transmission of various filter combinations and to re-set the base line of the recording system. A 1620 of low microphonic noise is used as an impedance changer to decrease the input capacitance and thereby improve the frequency characteristic, F. The voltage from the 1620 is amplified by three direct coupled pentode stages having a gain of 50, 30, and 200. The output of the last pentode operates a second impedance changer which feeds back a part of this output voltage into the photocell circuit through the sensitivity control. This provides inverse feedback which improves the frequency response and linearity of the amplifier. The second impedance changer is used to drive the vertical axis of the cathode ray oscillograph through a push-pull deflection stage. All circuit elements have been tested for linearity and grid current. With no feedback the amplification is linear over the oscillograph scale to 2 per cent. The grid current of the 1620 is 3×10^{-11} amperes. The photocell leakage current is 2×10^{-10} amperes at 320 volts. The full gain with no feedback is 100,000 or 35,000 mm. oscillograph deflection per volt input. The frequency response improves as the gain is decreased and the gain is set with due regard to the rapidity of the change of light absorption. It has been found that a frequency pass from zero to 20 cycles per second is the minimum permissible for this apparatus. The frequency response is uniform to 20 cycles per second at a gain of 8000 mm. per volt. The frequency response is maintained low so that the signal to noise ratio will be large. The line width on the oscillograph screen at full gain is 3 mm. or 3 per cent. of the available deflection. At lower values of gain the line width is about 1.5 mm. The

FIG. 13.

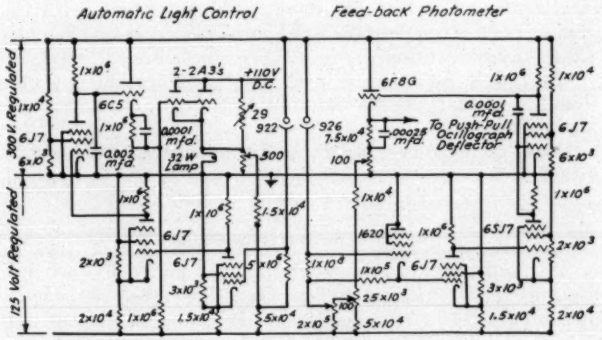


A typical curve showing the performance of the automatic light control and feedback photometer in measuring a rapid change in absorption. The curve shows in triplicate the disappearance of a 0.00025 per cent. solution of methylene blue in a 1 mm. tube in a half time of 0.05 seconds. The vertical axis is light absorption and the horizontal axis is time. The time markers are 1/50 second apart.

stability is sufficient to permit recording for two seconds at full gain with a drift of no more than 5 mm. The rate of drift varies with the condition of the heater battery and with the number of transients in the supply line. The gain of this particular type of single sided direct coupled amplifier is somewhat restricted by its sensitivity to changes in supply voltage and variations in resistance values.

Figure 13 shows a curve obtained from such an apparatus. It shows in triplicate the disappearance of color from a 0.00025 per cent. solution of methylene blue in a period of 0.05 seconds

FIG. 14.



Final light control and photometer circuits. Resistances are in ohms.

in a 1 mm. bore tube. While the range of the photometer could be pushed farther, other technical difficulties delay this.

(c) The Recording System.

A cathode ray oscilloscope has been chosen for a recording instrument as it permits the recording of simultaneous values of the two desired quantities, flow rate and light absorption, as a continuous curve. In the present apparatus the kinetic curves appear in the form of a non-repeating transient of a duration not less than 0.01 second and a spot travel of no more than 5 meters per second.

The present apparatus employs a RCA 909 5 inch tube which has a long persistence screen. The tube is operated at a total voltage of 2,000 which is obtained from a voltage regulated supply as shown in the RCA Handbook for Iconoscopes. This is used to prevent any change in deflection sensitivity due to line voltage changes. Automatic brilliancy control is also provided so that the trace for negative values of acceleration of the flow appears much brighter than that for positive values. Such a circuit is shown by Cossor, England. Figure 29 shows the action of the brilliancy control. It is desirable to remove the record obtained with positive values of acceleration because this often simply represents clearing used reactants out of the observation tube and involves a greater total error than does the curve obtained with negative values of acceleration.

Push-pull deflection is used and the deflection is proportional to the deflecting voltage to 2 per cent., the accuracy of measurement.

Most of the curves shown in this paper were taken from a 5 inch Cossor gas-focused tube operated at 600 volts. The inherent error of this tube is about 3 per cent.

5. The Measurement of Flow Velocity.

A small generator or a bar magnet and coil have been used as flow velocity indicators. The most satisfactory measurement of flow velocity for the manually driven units was obtained by taking the derivative of the displacement of the syringe plungers. The displacement of the syringe plungers was obtained by the change in voltage across the arm of a linear potentiometer. The arm of the potentiometer was connected directly to the syringe plungers by a chain wrapped around a drum on the shaft of the potentiometer. There was a 250 volt variation due to the four inch travel of the syringe plungers. This was fed into a circuit which takes the derivative of the voltage in the manner described by Shuck.[12] The expression for the circuit which consists of a condenser, C, and a resistor, R, in series is:

$$e = \frac{1}{C}\int i dt + Ri, \tag{58}$$

$$\frac{de}{dt} = \frac{i}{C} - R\frac{di}{dt}; \qquad \frac{di}{dt} - \frac{i}{RC} = \frac{1}{R}\frac{de}{dt}, \tag{59}$$

whence

$$i = e^{-t/RC}\left[\int \frac{1}{R} \times \frac{de}{dt} e^{t/RC} dt + C_1\right], \tag{60}$$

$$i = e^{-t/RC}\left[\frac{1}{R} \times \frac{de}{dt} RCe^{t/RC} + C_1\right], \tag{61}$$

if $i = 0$ when $t = 0$

$$i = \frac{de}{dt} C + C_1 e^{-t/RC}, \tag{62}$$

$$C_1 = -\frac{de}{dt} C, \tag{63}$$

$$i = \frac{de}{dt} C[1 - e^{-t/RC}]. \tag{64}$$

Voltage available for amplification

$$= RC\frac{de}{dt}[1 - e^{-t/RC}]. \tag{65}$$

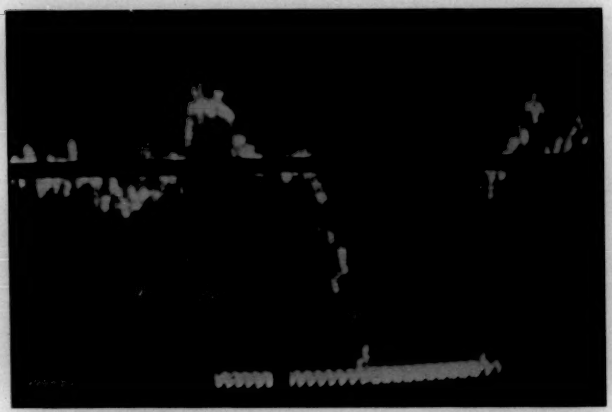
$RC\frac{de}{dt}$ represents the desired voltage while $1 - e^{-t/RC}$ is a transient which will interfere if RC is large. Using a small value of RC, the transient will be short-lived but the voltage output will be small. Typical values are $C = 0.1$ mfd. and $R = 5000$ ohms for which the transient is $\frac{1}{3}$ over in 0.0005 seconds.

The difficulties of this flow base were the tendency to amplify the ripple in the supply voltage and the irregularities in the winding of the linear potentiometer. This latter was eliminated by reducing high frequency response of the amplifier of the voltage $RC\frac{de}{dt}$. These irregularities are of a higher frequency than the voltage desired by a factor corresponding to the number of turns of wire in the linear potentiometer. In the actual case this factor was 200 so that not much difficulty was experienced.

This velocity indicator can be calibrated in a number of ways. The first is to simply rotate the arm of the potentiometer at known speeds by a constant speed drive.

A second method of calibration consists of measuring the flow velocity indication as a function of time as in Fig. 15. It is assumed that the indication is linearly related to the flow velocity but the magnitude of the constant is unknown. The average value of the indication can be calculated either by graphical integration or by assumption of a mean value for

FIG. 15.



Calibration of flow velocity indicator. Time markers 1/60 seconds.

the indication. The duration of the discharge is determined by the time marking on the photograph. The quantity discharged during this interval is measured by the graduations on the syringes. Thereby the volume discharged per unit time, V_1, is calculated and the indication of the flow velocity indicator is measured. The constant of the indicator is the quotient of these two quantities.

From Fig. 15 the length of time that the flow was maintained is 0.755 seconds. The volume discharged was 2 cc., hence $V_1 = 2.65$ cc./sec. The mean deflection over the

interval was taken to be 35 mm. Hence the constant is 13.2 mm. per cc. per second for the particular value of gain of the indicator. The value calculated by the next method was 14.2 mm. per cc. per second. This value is readily converted into mm. per meter per second linear flow velocity by multiplying by A_0, the area of the observation tube.

The third method is electrical. A voltage which is a known function of time is applied to the derivative circuit. As a saw-tooth wave is easily obtainable, it is applied to the derivative circuit and the derivative of the saw-tooth wave is plotted as a function of time on the oscillograph screen. As the saw-tooth was a linear function of time, obtained in a manner described below, the plot shows two perpendicular

TABLE IV.

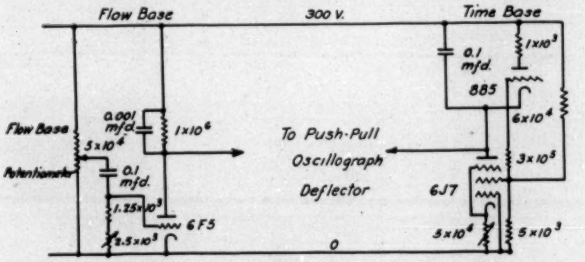
Calibration of Flow Velocity Indicator.

Oscillograph Sensitivity mm./volt Input.	Frequency Cycles per Second.	Breakdown Voltage of 885.	Oscillograph Deflection mm.	$\frac{de}{dt}$	Voltage at Input.	*RC* Observed.	*RC* Installed.
68	25	120	94	3000	1.38	4.6×10^{-4}	5×10^{-4}
68	16.7	120	64	2000	0.94	4.7×10^{-4}	5×10^{-4}
68	12.5	120	46	1500	0.68	4.5×10^{-4}	5×10^{-4}
68	10	120	40	1200	0.59	5.0×10^{-4}	5×10^{-4}
						4.7×10^{-4}	

lines joined in a right angle or a curve depending upon the length of the transient. The displacement of the derivative line from the origin is measured as is the frequency and amplitude of the saw-tooth wave. The frequency is measured against 50 or 60 cycle A.C. and the amplitude from known characteristics of the thyratron whose breakdown point controls the amplitude. In this way, $\frac{de}{dt}$ and the voltage output of the amplifier is obtained. The latter, divided by the gain of the amplifier gives the voltage input. From formula (65) this voltage input divided by $\frac{de}{dt}$ should equal RC. Table IV indicates that the formula correctly expresses the magnitude of the derivative over a considerable range.

To calculate the actual flow rate from a given oscillograph deflection we proceed as follows: First, we get the ratio between the travel of the syringe plungers and the fluid in the observation tube. The total area of two syringes is 2×15.9 mm^2. $= 31.8$ mm^2. The area of the observation tube is 0.788 mm^2. The ratio is 40.4. A 70 mm. travel of the potentiometer arm corresponds to a 250 volt change in the potential of the arm. As the arm is directly connected to the syringe plungers this corresponds to 40.4×70 mm. $= 2930$ mm. of fluid travel in the observation tube. Thus we get an input of 88.4 volts per second for every meter per second of flow. The deflection in mm. of the oscillograph screen for

Fig. 16.



Circuit of flow velocity indicator and time base oscillator.

every meter per second is then $88.4 \times 4.7 \times 10^{-4} \times 68 = 2.82$ where 68 is the deflection sensitivity of the oscillograph and its amplifier in mm./volt. In this way the instantaneous flow rate is obtained with a very simple and compact apparatus. The circuit is given in Fig. 16.

The constants used to obtain 14.2 for the second method were as follows. 300 volts were applied to potentiometer, RC was 3.75×10^{-3}, and the deflection sensitivity was 28.2 mm. per volt.

We will conclude this discussion of the horizontal axis by describing the circuit used for stopped flow observation and for calibrating the flow base circuit just described. It is a modified oscillograph time base circuit adapted to operate at

frequencies from 1/10 to 60 cycles per second. As A.C. coupling devices are not suitable for less than a few cycles per second, this circuit is directly coupled to the oscillograph. The conventional pentode limited charging circuit is used so that the wave will be a linear function of time for all frequencies. An 885 is used to rapidly discharge the condenser when a predetermined voltage across the condenser is reached.

IV. THE POSSIBLE RANGE OF THE METHOD.

1. The Magnitude of the Problem.

As far as this method is concerned, chemical reactions may be divided into two classes: Reactions whose rate is independent of the initial concentrations of the measured substance and reactions whose rate is reduced by reducing the initial concentration of the measured substance. The monomolecular breakdown of an enzyme substrate compound will be used as an example of the first case while any typical bimolecular process would serve as an example for the second case. Haldane [5] has shown that the mean life time of the catalase-hydrogen peroxide molecule is approximately 10^{-7} seconds. If this figure is correct, it will be necessary to measure a time of this order by the flow method to study the kinetics of this reaction. The formation of this molecule must occur in a still shorter time than this. Moelwyn-Hughes [6] has shown that the collision number for potassium and chloride ions is 5.17×10^{11} per second for a one molar solution under certain conditions. Assuming that this number sets a limit to the possible rate of reaction, we can see that a 10^{-5} molar solution would require a measurement of 10^{-6} seconds or the same order of magnitude of time as that required by the enzyme problem.

2. The Necessary Range of the Flow Method.

(a) Time.

An attempt will be made to state the conditions under which the flow method is to operate from a knowledge of the important factors disclosed in the previous analysis. It is assumed that a time of 10^{-6} seconds is adequate for the catalase-hydrogen peroxide reaction. Expression (1) applies as this is a time limited case. Later discussion will show that

mixing could be expected to be reasonably complete 2 mm. from the mixing chamber and that $\frac{A_0}{V_1}$ can be replaced by $\sqrt{\frac{0.330}{\Delta P}}$ under the conditions of measurement. Assuming these values do not change when the flow velocity is greatly increased, it follows that the pressure drop required to measure a time of 10^{-6} seconds is 1.3×10^6 pounds per square inch and the flow velocity is 2000 m./sec. At present the highest flow velocity attainable with due regard to all other factors of the method is 25 m./sec. It must be remembered that the formulae used to calculate these values have been assumed to hold true over 80 times the experimental range.

(b) Substance.

The ultimate dilution of a reactant that can be measured is calculated from (12). The present limits to dilution of reactants have been measured and it is found that a 10^{-7} molar solution of methylene blue and a 10^{-5} molar solution of iodine can be measured with an accuracy of 10 per cent. in a 1 mm. trough. This does indicate that a refinement of one hundred fold in the photoelectric system should bring the most rapid chemical processes within the range of this apparatus provided the reactants have as intense absorption bands as those mentioned.

(c) Temperature.

It is not felt that operation at low temperatures would extend the range of the apparatus to any great degree. The reactions measured by Lewis [8] at $-60°$ C. would be easily measurable at room temperature by this apparatus if his temperature coefficients are constant since the bimolecular velocity constant at 20° is about 10^4 for the most rapid reaction Lewis measured. In cases where the energy of activation is very small, the change of rate of reaction with temperature is almost negligible.

Temperature control over this range to determine order of magnitude of energy of activation would be a very valuable feature.

V. DISCUSSION.

An analysis of the theoretical limitations of the flow method has shown that relatively simple relations between the fundamental variables may be obtained. In a case where the time measurable by the system must be made as small as possible, the efficiency of mixing and the maximum flow rate are the important factors cf. (2). As the maximum flow rate is limited by the pressure drop involved and by cavitation of the flow stream, experimental studies have been made of both these factors. It has been shown that the pressure drop due to a combined mixing chamber and short observation tube obeys a parabolic relation between pressure drop and flow velocity. In such cases it has also been shown that the flow velocity obtainable for a given pressure drop is approximately constant regardless of the diameter of the observation tube bore. The strength of materials and driving power available then sets the limit on the attainable flow velocity. In cases where photoelectric sensitivity is important, mechanical and electrical effects on the photoelectric system may limit the desirable driving power. The cavitation of the flow stream is a limitation on the flow velocity in that it obscures photoelectric observation by light transmission. Studies of the effect of jet placement on cavitation have made possible a four-fold increase in the flow velocity attainable without cavitation. It has been pointed out that a bell-mouth observation tube should eliminate cavitation.

While the factors affecting the time required to mix the reactants have not been completely determined or related, these experiments and those of Roughton and Millikan [2] indicate that the time required to mix the reactants decreases with an increase of flow velocity or kinetic energy loss in the mixer. The justification for this statement is that the efficiency of mixing at a given distance from the mixing chamber does not decrease with flow velocity but tends to increase for the types of mixers tested.

In a case where the substance to be studied has not only a high rate of reaction but also a small extinction coefficient or concentration, the relation between the variables cf. (14) shows that light intensity, the photocell sensitivity, the photocell load resistance and the frequency pass of the photocell

amplifier are additional important factors. The development of automatic light intensity control has permitted the use of much higher values of light intensity. A limitation to the light intensity is that due to the variation of the supply voltage. These variations have been considerably reduced by the use of a photoelectric control circuit which supplies a part of the lamp voltage and thereby corrects changes in the light intensity falling on the control photocell. The ultimate limit of this control circuit is identical to that for the absorption measurement circuit. The photocell sensitivity is limited by available photocells but some choice of spectral characteristics is permitted. The photocell load resistance can be increased until the drop across it is comparable to 1/20 volt. There should be small difficulty due to grid currents as the value of the grid resistance need not be excessive using light sources and phototubes now available. In the case where the amount of substance is not important the speed of response of the amplifier should be made as small as possible.

In this and the following case the ratio of slit length to the mean distance from the point of mixing to the point of observation has become limited since this ratio and the extent of reaction determine the slit length error. This ratio also appears as a factor determining the range of the apparatus. These relations decrease the emphasis on observing very close to the mixing chamber.

In a case where the substance to be studied has a high rate of reaction and a small extinction coefficient or a low concentration, and is obtainable in a limited quantity, it is necessary to increase the speed of response of the photoelectric amplifier cf. (21). As photoelectric light control has made possible the elimination of slow or rapid fluctuations in the light source, the absorption measurement system has been improved so as to measure rapid changes in light intensity. The use of inverse feedback has made possible a high response speed.

Three methods of obtaining high fluid economy have been analyzed and include the Hartridge-Roughton [1] continuous flow method with infinitely short starting and stopping periods, the accelerated flow method, and the stopped flow method. The first method has probably already been developed to its peak of efficiency by Millikan [2] who obtained a

kinetic curve from 20–30 cc. of each reactant. The accelerated flow method obtains a kinetic curve while the flow is accelerating through a desirable series of values. The flow velocity and corresponding extent of reaction are measured electrically and plotted in the form of a kinetic curve on the screen of a cathode ray tube. In this way a kinetic curve may be obtained from 1/2 cc. of each reactant. The stopped flow method uses the same mixing and flow technique of the accelerated flow method but uses values of acceleration of the flow such that the flow is stopped in a time short compared to the half-time of the reaction to be measured. The extent of reaction of the stopped reactants is plotted directly against time on the screen of the cathode ray tube. One quarter cc. of each reactant is usually sufficient for a complete kinetic curve.

VI. SUMMARY.

Relations between the variables of the flow method have been developed for time limited, time and substance limited, and time, substance, and quantity limited conditions of operation. The last relation has shown that the quantity of fluid required may be reduced by increasing the speed of response of the system for measuring the extent of reaction. This factor has permitted the development of the accelerated and stopped flow methods which give a continuous record of kinetic data from small quantities of fluid. The increase of speed of response has been accomplished by the development of a photoelectric light control circuit and by the use of inverse feedback in the light absorption measurement circuit. A study of the factors influencing pressure drop and cavitation in mixing chambers and observation tubes has resulted in improvements in the range of the apparatus.

VII. CONCLUSIONS.

1. The flow velocity is the most important variable of the flow method and it is limited by the driving force available, the onset of cavitation, and the effect of the driving force on the electro-optical system.

2. The photocell sensitivity, light intensity, and response speed of the amplifier are limitations on the measure-

ment of substances having small extinction coefficients or concentration.

3. The response speed of the photoelectric system must be made high if the quantity of substance is limited.

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NOTES FROM THE NATIONAL BUREAU OF STANDARDS.*

PLASTIC CALKING MATERIALS.

In masonry buildings, as well as in some other types of construction, joints will be found which vary in width because of temperature changes, settlement, etc. Mortar does not "give" enough to maintain watertight or airtight joints in such cases. Plastic calking compounds are, therefore, used, because they can adjust themselves to comparatively large structural movements, their value depending mainly on their ability to remain plastic.

A study of watertight joint fillers is being made at the Bureau mainly for the purpose of devising tests which will enable the purchaser to determine the serviceability of such products. Inspections of buildings and joint specimens after several years of exposure to the weather have been made and the types of failure studied. As a result of this work it has been concluded that tests for shrinkage, rate of hardening, bond, tenacity, staining, and slumping should give good indications of performance. Since calking compounds are commonly used in contact with porous materials, the absorptive properties of which affect the performance, it is necessary to employ an accessory porous material in the testing. For this purpose a certain limestone has been selected because of its uniformity. The tests require three specimens for each sample and on these, eight different determinations can be made.

Chemical analyses on a large number of proprietary compounds have indicated that a variety of compositions are used in their manufacture. Most of these consist of finely ground materials such as whiting, silica, talc, etc., mixed with blown or polymerized oils. Fish, soy bean, linseed, and tung oils are those most commonly used. Cottonseed and rapeseed oils are employed in some mixtures, while there are a few brands in which the vehicle consists of rosin, tallow, or synthetic resin. Most of the compounds contain some volatile

* Communicated by the Director.

thinner, and practically all incorporate 5 to 10 per cent. of fibrous material—usually asbestos. A study of the effects of various ingredients, by means of experimental mixtures, indicates that proper pretreatment of the oil is of first importance and that care must be exercised in selecting fillers as well as in avoiding an excess of volatile thinner. Certain factors which affect the performance of plastic calking compounds in service have been studied. Compounds that give satisfactory service in one type of masonry do not always give similar results in other types. Often very porous masonry absorbs less of the vehicle than much denser materials, because the capillary forces in fine pores are higher than in large ones. A compound giving satisfactory results in wide joints may fail entirely in narrow ones. Primers may reduce the shrinkage of mixtures having pronounced staining characteristics but they sometimes interfere with the bond. In general, a properly prepared calking compound will give as good results without a primer as when the surfaces are primed.

The complete account of this work has been published as Building Materials and Structures Report BMS33, copies of which are obtainable from the Superintendent of Documents, Government Printing Office, Washington, D. C., at 10 cents each.

SERICIN IN RAW SILK.

Raw silk fibers consist of at least two proteins, silk fibroin and silk sericin. The latter forms a coating over the fibroin and constitutes 15 to 30 per cent. of the total weight of the raw fiber. In practical silk processing, the sericin is generally allowed to remain on the fiber until the fabric is ready to be dyed. In this way, it acts as a protective coating for the silk in the weaving or knitting operations.

Removal of the sericin is usually accomplished with hot soap solutions. The results of numerous studies of this process led earlier investigators to a variety of concepts concerning the state and properties of the sericin in the raw silk fiber. Some stated that the sericin is a single protein substance, whereas others claimed it to be a mixture of proteins which they designated as sericins A, B, etc. The latter concept formed the basis for further claims concerning the desirability

of retaining certain fractions of the sericin to improve some ultimate properties of the silk. As many of these claims were based on insufficient experimental evidence, it seemed desirable to make a more extensive investigation of the question of the possible existance of several fractions of the sericin in raw silk.

The results of such an investigation by Henry A. Rutherford and Milton Harris, and reported in the *Journal of Research* for April (RP1290) show that the relative yields of the so-called sericins A and B, obtained after treatment of silk in an autoclave, were dependent on the duration of the treatment. Practically all of the sericin removed in the early stages of autoclaving was in the form generally designated as sericin B. On continuing the treatment, this fraction was rapidly converted into the more soluble form, sericin A. Analyses of the fractions, obtained after autoclaving the silk for different lengths of time, showed that the alleged sericins A and B are not definite chemical entities, but are substances the chemical compositions of which vary with the duration of the autoclave treatment. It is concluded from these studies that the sericin in raw silk does not exist as a mixture of fractions, but that the fractions are artifacts which result from the hydrolytic decomposition of the naturally occurring sericin during its removal from the raw fibers.

SIZE OF PORES IN PAPER.

Many workers have been interested in determining the size of the pores, or tiny passages through paper, and have expended considerable effort in trying to measure their size. Such knowledge is valuable in problems involving the saturation of paper with liquids, in the use of filtering media, in the study of volumetric composition, in the design of paper for particular uses, and in other problems requiring a knowledge of the structure of paper.

The methods most used in attempting to measure the size of the pores in paper are of three general types: (*a*) those depending upon a measurement of the rate of efflux of fluids; (*b*) those depending upon a measurement of the rate of rise of liquids in vertical strips of paper; and (*c*) those depending upon

a measurement of the capillary pressure involved in the penetration of paper by liquids.

As described in the *Journal of Research* for April (RP1292), F. T. Carson of the Bureau's Paper Section, has developed a new method which takes advantage of the fact that the friction between a gas and the walls of a capillary tube through which it flows varies with the pressure of the gas. A well-known theoretical equation designed to describe the flow of a gas through a capillary tube is used in formulating an expression for the average effective radius of the pores in a sheet of paper, in terms of the air permeability at different pressures. With this method, therefore, it is only necessary to determine the air permeability accurately at two different pressures, in order to calculate the size of the pores. Means of accurately measuring the air permeability of paper have previously been described.

RP1292 includes experimental data on five papers, together with the calculated value of the average effective pore radius in each case. The values are in the neighborhood of a thousandth of a millimeter.

ENERGY RELATIONS IN LEAD STORAGE BATTERIES.

A knowledge of the thermochemical properties of sulfuric acid is needed as a basis for calculating heats of reaction. The electromotive force of a storage battery varies with the heat content of solutions throughout a rather wide range of concentrations. The battery problem has particular interest because the heat of reaction can be calculated in either of two ways, and comparison can be made of results based on entirely independent thermochemical and electrochemical data. The connecting link is the well-known equation of Gibbs-Helmholtz.

The thermochemical side of the problem is concerned with the heat of formation of the solid constituents of the cell, and the relative partial molal heats of sulfuric acid and water. It has been found possible to extrapolate the relative apparent molal heats of solution to infinite dilution and new calculations of the partial quantities have been made. At infinite dilution the battery reaction is identical with the calorimetric reaction.

The heat of reaction at finite and useful concentrations of the working battery can be calculated on the basis of these data.

On the electrochemical side of the problem, new experimental data for the electromotive force and its temperature coefficient are now available. These have engineering applications in the operation of floating batteries which are becoming increasingly important as they are superseding batteries formerly operated in cycle service. Computations of the heat of reaction by the Gibbs-Helmholtz equation, employing the best data, has yielded results which are in surprisingly good agreement with the results of thermochemical calculations. The average difference over the whole range of acid concentrations which are usable in storage batteries is only $\pm$ 0.12 per cent.

Using similar methods for calculating the partial molal volumes of sulfuric acid it was found that the effect of pressure on the electromotive force is too small to be of engineering significance. This answers a question which arises occasionally in connection with the use of batteries at high altitudes.

RP1294 by D. Norman Craig and George W. Vinal, in the April number of the *Journal of Research*, contains the complete account of this investigation.

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pH IN ALKALINE CYANIDE PLATING BATHS.

For many years the pH of acid plating baths has been measured and controlled, especially in nickel plating, but only recently has attention been given to similar control of alkaline cyanide plating baths, to which it is more difficult to apply either the electrometric or the colorimetric method of measurement. In the *Journal of Research* for April (RP1291) M. R. Thompson describes comparative readings recently made on buffered alkaline chloride solutions with the hydrogen electrode which is free from salt error by definition, with a commercial glass electrode, and with three colorimetric sets. Readings of pH by the glass electrode were too low. Readings with the indicators were usually too high, varying with the indicator. Salt errors of the glass electrode and of the indicators thus determined were employed for approximate cor-

rections to readings on several cyanide copper solutions in which the hydrogen electrode could not be used. These were applied on the assumption that salt errors of alkaline chloride and cyanide are equal. Corrected readings by the two methods agreed approximately but not closely enough for standard corrections to be adopted at this time. Further experience with various plating baths may permit the adoption of such corrections. Meanwhile, it is recommended that investigators state the type and make of apparatus employed for obtaining any data published on the pH of alkaline cyanide plating baths, in order to correlate the results obtained by different observers.

TARNISHING OF STAINLESS STEELS.

The so-called "stainless" steels, which are currently so popular, derive their name from their behavior when exposed at ordinary temperatures to atmospheric conditions which result in the prompt tarnishing and rusting of ordinary iron and steels. This suggests that stainless steels are more resistant to initial oxidation, but this is not the case. Any piece of iron or steel, when it is first exposed to the atmosphere, is immediately covered with a thin film of oxide, sometimes called the passive film. This initial film on stainless steel protects the metal from further oxidation under these conditions and the surface remains bright because the film is so thin as to be invisible. On the other hand, the initial film on ordinary iron and steels does not prevent further oxidation, and the film increases in thickness until it becomes visible, i.e., the metal tarnishes. The resistance of stainless steel to tarnishing therefore is an indication of the protective action of the initial film of oxide, rather than of the complete absence of any oxidation.

The non-tarnishing property of stainless steel applies particularly to atmospheric exposure. When stainless steels are heated to elevated temperatures in air they develop temper colors as do ordinary irons and steels, although it requires a higher temperature or a longer time to develop a given temper-color on stainless steel. Under other conditions stainless steel may tarnish as readily or more readily than does ordinary iron

and steel, as was observed in some recent experiments conducted by Vernon C. F. Holm of the Bureau's Metallurgy Division, which involved heating specimens of various metals to temperatures between 700° and 800°C. in a high vacuum.

Under these conditions specimens of stainless steel, either the cutlery type with 12 per cent. of chromium or the familiar 18 chromium-8 nickel steel, were decidedly tarnished, whereas iron and many types of steel, including low-chromium steels with not more than 5 per cent. of chromium, remained bright. Not only did ordinary iron fail to tarnish under these conditions, but tarnish films which had been formed by prior heating of the specimens in air were completely removed by this treatment. Specimens of stainless steel could be annealed without tarnishing only at temperatures above 1000° C.

These results are representative of the relative stability of the oxide films on the two types of materials. At elevated temperatures and in vacuum the oxide films tend to decompose and this tendency increases with increasing temperature. Under the conditions of these experiments the film on ordinary iron or steel decomposed below 700° C. but the film on stainless steel was stable up to about 1000° C.

These observations are in accord with the facts observed in commercial practice, that it is more difficult to "bright-anneal" stainless steel than ordinary steel, although the stainless steel is easier to keep bright at ordinary temperatures.

Experimental Studies on Non-Fluid Lubrication.—In *Refiner and Natural Gasoline Manufacturer*, Vol. 19, No. 3, S. KYROPOULOS presents the third of his papers which discusses the various physico-chemical factors determining the behavior of bearing metals in non-fluid lubrication under the influence of local high temperatures and chemical reactions with the lubricant which are liable to occur. Journal polish is in general to be considered both as a mechanical protection against excessive cold work by greater smoothness, and as a physico-chemical protection by a protective anti-welding oxide layer. The coefficient of kinetic friction will be that of the oxidized metal. A new theory of bearing metals is presented, explaining the mechanical part played by the various constituents of a composite bearing metal. The load carrying capacity of a simple structure is calculated by stress analysis. The theory, derived from observation, provides a simple rule for the selection of bearing alloy components and indicates general rules for the relative particle size. In a well composed bearing metal for high speed and temperature operation it is the soft component which directly carries the load due to its higher thermal expansion. Due to the part played by volume expansion, the relative particle size of the constituents determines frictional and seizure properties. Fatigue resistance and mechanical strength increase, in a general way, with the melting point. For the same reason the work of deformation increases and so does the kinetic friction—comparing e.g. Sn and Al—because there is no kinetic friction without cold work and wear. It is for this reason that any pure high-melting metal must tend to "grip" any journal under certain conditions of clearance and temperature, no matter whether this "gripping" is accompanied by true seizure (welding, diffusion) or not.

R. H. O.

THE FRANKLIN INSTITUTE

STATED MONTHLY MEETING, APRIL 17, 1940.

The regular monthly meeting was held this evening at 8:15 o'clock, Mr. Walton Forstall, Vice-President, in the Chair.

The minutes of the previous meeting were approved as published in the April issue of the Journal.

The additions to membership since last report were as follows:

Honorary	2
Active	6
Associate	17
Student	12
Total	37

The Secretary announced that the series of lectures, given on alternate Fridays during the past several months under the general title "Meet Dr. Franklin" would terminate during the present week. Dr. R. A. Millikan would speak on "Dr. Franklin and Science" on Thursday evening and Dr. Carl Van Doren would close the series on Friday evening, his subject being "Dr. Franklin: Man of Letters."

Attention was also called to the Medal Day Meeting which will be held on Wednesday, May 15th, next. The medals will be awarded at the meeting in the afternoon and this ceremony will be followed by a subscription dinner to the medalists in the evening.

There being no further business the Chairman introduced Dr. W. F. G. Swann, Director of the Bartol Research Foundation, who presented his annual report of the work done during the past year. He described especially the following: researches upon the conduction of electricity in gases with particular relation to discharges initiated by different kinds of ionizing entities and to the properties of the Geiger-Mueller counters; researches on the nature of the field in magnetized iron; researches with cloud chamber and with Geiger counter systems on the characteristics of cosmic-ray mesotrons, particularly in their property of producing showers of charged particles; and the development of the Van de Graaff generator for investigations in nuclear physics.

The report was illustrated by lantern slides and experiments. On motion of Dr. Arthur L. Day, the thanks of the meeting were extended to Dr. Swann for his comprehensive report.

Adjourned,

HENRY BUTLER ALLEN
Secretary.

LIBRARY NOTES.

The committee on Library desires to add to the collections of the Institute any technical writings of members who have had occasion to publish such material.

Literary contributions from author-members will be gratefully acknowledged, properly inscribed and noted in the Journal of the Institute.

Photostat Service. Photostat prints of any material in the collections can be supplied on request. Orders received in the morning are filled the same day. The average cost for a print $8\frac{1}{2} \times 11$ inches is forty cents.

The library and reading room are open on Mondays, Tuesdays, Fridays and Saturdays from nine o'clock A.M. until five o'clock P.M., Wednesdays and Thursdays two until ten o'clock P.M. 975 readers made use of the facilities during the twenty-five days of March.

RECENT ADDITIONS.

AERONAUTICS.

PAVIAN, HENRY CHRISTENSEN. Experimental Aerodynamics. 1940.

AGRICULTURE.

TURNER, WAYNE I., AND VICTOR M. HENRY. Growing Plants in Nutrient Solutions. 1939.

ASTRONOMY.

FROST, GEORGE EDWIN. Planets, Stars, and Atoms. 1939.

OLCOTT, WILLIAM TYLER. Sunlore of all ages. 1914.

CHEMISTRY AND CHEMICAL TECHNOLOGY.

BURTON, DONALD, AND GEORGE F. ROBERTSHAW. Sulphated Oils and Allied Products. 1940.

CHAMOT, ÉMILE MONIN, AND CLYDE WALTER MASON. Handbook of Chemical Microscopy. Volume 2. Second Edition. 1940.

CHILD, ERNEST. The Tools of the Chemist. 1940.

Oil and Colour Chemists' Association. Varnish Making. 1940.

SAGE, BRUCE H., AND WILLIAM N. LACEY. Volumetric and Phase Behavior of Hydrocarbons. 1939.

TYLER, CHAPLIN. Chemical Engineering Economics. Second Edition. 1938.

ELECTRICITY AND ELECTRICAL ENGINEERING.

LOEB, LEONARD B. Fundamental Processes of Electrical Discharge in Gases. 1939.

ENGINEERING.

American Society for Testing Materials. 1939 Book of A.S.T.M. Standards. Part 1: Metals. 1940.

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Année Polaire Internationale 1932–1933. Participation française. Tomes 1–2. 1936–1938.

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SHUMARD, F. W. A Primer of Time Study. First Edition. 1940.

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DOUGHERTY, JOHN WOLFE. Pottery Made Easy. 1939.

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BIEGELEISEN, J. I., AND E. J. BUSENBARK. The Silk Screen Printing Process. First Edition. 1938.

British Journal Photographic Almanac. 1940.

KLEIN, ADRIAN BERNARD. Colour Cinematography. Second Edition, Revised and Enlarged. 1940.

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MILLIKAN, R. A. Cosmic Rays. 1939.

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WENDT, GERALD. Science for the World of Tomorrow. 1939.

STATISTICS.

TRELOAR, ALAN E. Elements of Statistical Reasoning. 1939.

STEAM ENGINEERING.

YEOMANS, EDWARD. Men, Steam and the Driven Wheel. 1939.

SUGAR.

Forschungsinstitut der Zuckerindustrie für Böhmen und Mähren in Prag. Bericht für das Jahr 1938–39. 1939.

South African Sugar Year Book. No. 10. 1939–40.

FINANCIAL STATEMENTS

as at December 31, 1939.

April 19, 1940.

To the Board of Managers of
The Franklin Institute,
Philadelphia.

We have examined the balance sheet of THE FRANKLIN INSTITUTE as of December 31, 1939, and the statements of income and expenses and general fund for the year then ended, and, without making a detailed audit of the transactions, have examined or tested accounting records of the Institute and other supporting evidence.

The income as reported in the accompanying statement of income and expenses is stated from the books of account. We did not verify the income from the Museum aggregating $75,601.24 as it is not susceptible of independent verification. The expenses were supported by proper vouchers. The buildings and equipment and investments are stated at cost or appraised values at date of acquisition, and do not purport to represent present day values. We did not, at the request of the controller, mail to debtors requests for confirmation of the uncollected balances of accounts receivable as of December 31, 1939.

Based upon the statement of income as set forth in the preceding paragraph, the stating of investments at cost or appraised values at dates of acquisition, and subject to confirmation of accounts receivable balances by debtors, in our opinion, the accompanying financial statements present fairly the position of The Franklin Institute at December 31, 1939, and the results of its operations for the calendar year, in conformity with generally accepted accounting principles applied on a basis consistent with that of the preceding year.

LYBRAND, ROSS BROS. & MONTGOMERY.

THE FRANKLIN INSTITUTE.

BALANCE SHEET, DECEMBER 31, 1939.

Assets.

Demand deposits in banks and cash on hand (not including cash in endowment trust funds)		$23,123.83
Accounts receivable:		
For memberships, subscriptions, exhibits, etc.	$12,742.02	
Due from officers and employees	1,172.93	
		13,914.95
Materials and supplies, at cost		10,047.13
Buildings and equipment, at cost, not including exhibits loaned and donated		4,091,250.95
		$4,138,336.86
Endowment fund investments, cash, etc.:		
Investments, at cost or appraised values at the dates of acquisition	$2,175,454.36	
Deposit in closed bank, less reserve	67,500.00	
Cash:		
Uninvested principal	14,873.28	
Unexpended income	5,989.66	
		2,263,817.30
		$6,402,154.16

Liabilities.

Accounts payable		$11,231.68
Deferred income from dues, donations, etc.		31,948.00
Contributed funds used for buildings, equipment, etc., as annexed		3,930,707.51
Stock outstanding:		
First class	$12,840.00	
Second class	70.00	
		12,910.00
General Fund account, as annexed		151,539.67
		$4,138,336.86
Endowment funds:		
Principal, as annexed	$2,257,827.64	
Unexpended income	5,989.66	
		2,263,817.30
		$6,402,154.16

GENERAL FUND ACCOUNT

for the year ended December 31, 1939.

Balance, January 1, 1939		$148,255.04
Add:		
Amount withdrawn from the Museum Reserve Fund Principal for capital and operating expenditures	$75,600.00	
Par value of 10 shares first class stock surrendered for cancellation	100.00	
		75,700.00
		$223,955.04
Less deficit for the year ended December 31, 1939		72,415.37
Balance, December 31, 1939		$151,539.67

INCOME AND EXPENSE ACCOUNT

for the year ended December 31, 1939.

Income.

Dues (prorated portion of annual dues), fees, etc.		$24,152.25
Less dues uncollected, prior years		348.00
		$23,804.25
Museum income:		
Museum admissions	$33,524.10	
Planetarium admissions	24,762.65	
Traveling shows, sale of guide books, etc.	17,314.49	
		75,601.24
Subscriptions to publications and advertising		6,631.75
Donations:		
Friends of Franklin	$52,893.59	
Less expenses	7,359.53	
		45,534.06
Administrative charges for services rendered The Bartol Research Foundation and The Biochemical Research Foundation		10,000.00
Miscellaneous income, net		996.03
		$162,567.33
Income from trust fund investments and distributions from estates, etc.		77,841.09
Total Income (*Carried Forward*)		$240,408.42

INCOME AND EXPENSE ACCOUNT (*Continued*)

Total Income (*Brought Forward*)			$240,408.42

Expenses.

	Salaries and Wages.	Other.	
Building operation and maintenance	$39,272.53	$32,797.97	
Library	14,416.00	4,948.75	
Meetings	—	2,445.71	
Office and general	54,475.41	12,023.48	
Machine shop	822.65	397.33	
Museum	103,714.05	37,642.18	
Publications	—	14,036.93	
Science and The Arts	3,840.00	253.96	
Traveling expense	—	979.44	
Annuities	3,125.00	—	
Membership badges, certificates, etc.	—	96.22	
	$219,665.64	$105,621.97	
		$325,287.61	
Less donations received for museum salaries and expenses		12,463.82	
			312,823.79
Deficit for the year			$72,415.37

SUMMARY OF CHANGES IN ENDOWMENT FUNDS

for the year ended December 31, 1939.

Balances, January 1, 1939			$2,324,023.21
Add:			
Amounts received from:			
William M. Vermilye	$ 2,650.00		
Estate of Arthur H. Lea	50,000.00		
		$52,650.00	
Life membership fees		2,500.00	
Miscellaneous		15.77	
			55,165.77
Total (*Carried Forward*)			$2,379,188.98

SUMMARY OF CHANGES IN ENDOWMENT FUNDS (*Continued*)

Total (*Brought Forward*)			$2,379,188.98
Deduct:			
Losses, net of profits, on disposal of investments:			
Losses	$35,474.55		
Profits	2,029.23	$33,445.32	
Amounts withdrawn from Funds:			
From Museum Reserve Fund for capital and operating expenditures	$75,600.00		
From Boyden Premium Fund for award	500.00		
From Vermilye Medal Fund for cost of medal design and die	476.31	76,576.31	
Amounts received as a distribution from principal of the John G. Meigs Bequest, credited to John G. Meigs Memorial Fund (income account)		11,339.71	
			121,361.34
Balances, December 31, 1939			$2,257,827.64

CONTRIBUTED FUNDS RECEIVED FROM BENJAMIN FRANKLIN MEMORIAL, INC.,

for the year ended December 31, 1939.

Balance, January 1, 1939			$3,922,550.89
Add:			
Pledges collected	$7,731.22		
Amounts received from Treasurer of Benjamin Franklin Memorial, Inc.		425.40	
			8,156.62
Balance, December 31, 1939			$3,930,707.51

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THE BARTOL RESEARCH FOUNDATION OF THE FRANKLIN INSTITUTE.

CONDENSED FINANCIAL REPORT

as at September 30, 1939.

December 1, 1939.

To the Board of Directors of
The Franklin Institute,
Philadelphia.

We have examined the balance sheet of THE BARTOL RESEARCH FOUNDATION OF THE FRANKLIN INSTITUTE as at September 30, 1939, and the statement of income and expenses for the fiscal year then ended, have reviewed the system of internal control and the accounting procedures of the Foundation and, without making a detailed audit of the transactions, have examined or tested accounting records of the Foundation and other supporting evidence, by methods and to the extent we deemed appropriate.

In our opinion, the accompanying balance sheet and related statement of income and expenses present fairly the position of The Bartol Research Foundation of The Franklin Institute at September 30, 1939, and the results of its operations for the fiscal year, in conformity with generally accepted accounting principles applied on a basis consistent with that of the preceding year.

LYBRAND, ROSS BROS. & MONTGOMERY.

THE BARTOL RESEARCH FOUNDATION OF THE FRANKLIN INSTITUTE.

BALANCE SHEET, SEPTEMBER 30, 1939.

Assets.

Cash:			
In bank and on hand, general fund		$3,646.31	
Unexpended income:			
Henry W. Bartol Bequest	$7,493.90		
Investment of unexpended income fund	9,370.50	16,864.40	
			$20,510.71
Investments of unexpended income fund, at cost			223,852.48
Accounts receivable			41.13
Building and equipment, at cost:			
Laboratory building		$226,591.05	
Furniture and fixtures		14,874.93	
Equipment:			
Laboratory	$83,681.03		
Less allowance for depreciation	7,218.22	76,462.81	
Machine shop	$16,849.39		
Less allowance for depreciation	2,168.51	14,680.88	
Building		375.00	
Office		3,013.47	
Library		1,057.65	
			337,055.79
			$581,460.11

Investments (at cost or appraised values at dates of acquisition) and cash of principal of trust funds:

	Investments.	Cash.	
Henry W. Bartol Bequest	$1,334,800.41	$ 855.86	
Pension fund	79,414.52	1,361.75	
	$1,414,214.93	$2,217.61	
			1,416,432.54
ASSETS (*Carried Forward*)			$1,997,892.65

BALANCE SHEET, SEPTEMBER 30, 1939 (*Continued*)

Assets (*Brought Forward*)			$1,997,892.65
Collateral Trusts.			
Cash:			
Uninvested principal	$10,313.59		
Undistributed income	2,550.27	$12,863.86	
Investments (at cost or appraised values at dates of acquisition):			
Helene Bonar Bartol Trust	$296,968.95		
Lucy Cheyney Farr Trust	149,960.97		
Katherine de Monclos Trust	149,717.55	596,647.47	
			609,511.33
			$2,607,403.98
Liabilities.			
Accounts payable			$2,811.61
General Fund account:			
Balance, October 1, 1938		$559,498.46	
Cancellation of allowances provided in prior years for depreciation on laboratory equipment other than storage battery		10,144.11	
		$569,642.57	
Excess of income over expenses for the year ended September 30, 1939, as annexed		9,005.93	
Balance, September 30, 1939			578,648.50
			$581,460.11
Endowment Funds:			
Henry W. Bartol Bequest		$1,335,656.27	
Pension fund		80,776.27	
			1,416,432.54
			$1,997,892.65
Collateral Trusts.			
Principal:			
Helene Bonar Bartol Trust	$301,054.50		
Lucy Cheyney Farr Trust	153,051.60		
Katherine de Monclos Trust	152,854.96	$606,961.06	
Undistributed income		2,550.27	
			609,511.33
			$2,607,403.98

STATEMENT OF INCOME AND EXPENSES

for the fiscal year ended September 30, 1939.

Income.

Income received from investments	$61,558.52

Expenses.

	Salaries and Wages.	Other.	
Building operation and maintenance	$1,100.00	$3,318.64	
Library	—	726.35	
Administrative and general	15,200.00	2,206.25	
Laboratory and machine shop	23,110.61	4,067.25*	
Publications, reprints	—	402.70	
Traveling expense	—	206.00	
Administrative charge, The Franklin Institute	—	5,000.00	
	$39,410.61	$15,927.19	
			55,337.80
			$ 6,220.72
Other income:			
Profits, net of loss, on the sale of income investments			2,785.21
Excess of income over expenses for the year, transferred to General Fund Account			$ 9,005.93

* Includes provision of $949.20 for depreciation of laboratory equipment.

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THE BIOCHEMICAL RESEARCH FOUNDATION OF THE FRANKLIN INSTITUTE.

CONDENSED FINANCIAL REPORT

as at August 31, 1939.

December 1, 1939.

To the Board of Managers of
The Franklin Institute,
Philadelphia.

We have examined the balance sheet of THE BIOCHEMICAL RESEARCH FOUNDATION OF THE FRANKLIN INSTITUTE as at August 31, 1939, and the statements of expenses and income and the general fund account for the fiscal year then ended, have reviewed the system of internal control and the accounting procedures of the Foundation and, without making a detailed audit of the transactions, have examined or tested accounting records of the Foundation and other supporting evidence, by methods and to the extent we deemed appropriate.

In our opinion the accompanying balance sheet and the related statements of expenses and income and general fund account present fairly the position of The Biochemical Research Foundation of The Franklin Institute at August 31, 1939, and the results of its operations for the fiscal year, in conformity with generally accepted accounting principles applied on a basis consistent with that of the preceding year.

LYBRAND, ROSS BROS. & MONTGOMERY.

THE BIOCHEMICAL RESEARCH FOUNDATION OF THE FRANKLIN INSTITUTE.

BALANCE SHEET, AUGUST 31, 1939.

Assets.

Cash:		
In general checking account and on hand	$11,093.82	
Unexpended cash of funds available for current operations:		
Biochemical Research Foundation	$38,067.11	
Emma M. Schaible Bequest	1,479.60	39,546.71
Unexpended cash of funds available for bonuses to employees (see contra)	20,246.30	
		$70,886.83
Investments, at appraised values at dates of acquisition:		
Biochemical Research Foundation	$183,500.00	
Emma M. Schaible Bequest	1,698.00	
		185,198.00
Equipment, at appraised value July 1, 1935, with subsequent additions at cost:		
Research apparatus and equipment	$139,933.74	
Improvements to leased property (less provision of $313.89 for amortization)	12,116.95	
Cyclotron experiment	23,699.39	
Library books	4,796.90	
		180,546.98
		$436,631.81

Liabilities.

Accounts payable	$1,189.56
Unexpended income from investments, available for bonuses to employees (see contra)	20,246.30
Deferred income, donation applicable to Contingent Fund expense during the year ending August 31, 1940	2,500.00
General Fund Account, as annexed	412,695.95
	$436,631.81

STATEMENT OF GENERAL FUND ACCOUNT
for the fiscal year ended August 31, 1939.

Balance, September 1, 1938	$516,814.69
Add:	
Appraised value of 300 shares United States Rubber Company first preferred stock, received as donation	31,387.50
	$548,202.19
Less, excess of expenses over income available for purposes of the Foundation, for the year ended August 31, 1939, as annexed	135,506.24
Balance, August 31, 1939	$412,695.95

STATEMENT OF EXPENSES AND INCOME
for the fiscal year ended August 31, 1939.

Expenses.

	Salaries and Wages.	Other.	
Building operation and maintenance		$11,806.70*	
Administrative and general	$26,753.34	2,872.73	
Laboratory	86,733.81	10,170.16	
Cyclotron	9,870.56	3,109.93	
Publications and printing		768.62	
Dues and subscriptions		848.01	
Traveling and entertainment		1,337.20	
Administrative charge, The Franklin Institute		5,000.00	
Miscellaneous		139.14	
	$123,357.71	$36,052.49	$159,410.20

Income.

Donation	$2,500.00	
Income received from investments, Emma M. Schaible Bequest	209.41	
Royalties received on sales of book, "Cancer and Diet"	70.04	
	$2,779.45	
Other income, Profits, net of loss, on sales of investments	21,124.51	
		23,903.96
Excess of expenses over income for the period, transferred to General Fund account		$135,506.24

* Includes provision of $313.89 for amortization of improvements to leased property.

NOTES FROM THE BARTOL RESEARCH FOUNDATION.

THE TRANSITION EFFECT FOR LARGE BURSTS OF COSMIC-RAY IONIZATION AND THE NUMBER OF PRIMARY ELECTRONS OF VERY HIGH ENERGY.*

BY

C. G. MONTGOMERY AND D. D. MONTGOMERY.

Bursts of cosmic-ray ionization were observed in the open air and under heavy roofs, with and without a one-cm lead plate over the ionization chamber. The increase in the number of bursts in the presence of the lead under heavy roofs is interpreted as an increase in the number of rays in the showers from the roof, while in the open air the bursts from the lead probably originate to a large extent from the action of electrons of high energy which are not members of cascade showers starting at the top of the atmosphere. If the bursts from the atmosphere with no lead present are to be accounted for by the assumption that they are parts of extensive cascade showers, it is possible to derive the number and energy distribution of the primary cosmic-ray electrons of energies of the order of 2×10^{15} electron volts.

RECENT STUDIES AT HIGH ELEVATIONS.†

BY

S. A. KORFF.

Certain phases of counter technique are reviewed. The conditions necessary to make and operate reliable proportional counters are discussed. It is shown that certain mixtures of gases, notably argon-carbon tetrachloride and argon-boron trifluoride, when used in counters give these the property of producing large pulses over considerable voltage ranges below the threshold. The size of the pulse (in volts) will be

* An abstract of an article published in full in *Phys. Rev.*, **56**, 640 (1939).

† An abstract of an article published in full in *Reviews of Modern Physics*, **11** 211 (1939).

roughly proportional to the amount of ionization produced in the counters by the passage of the ionizing particle being studied. Because of this proportionality, these counters can, for example, distinguish between alpha- and beta-rays over considerable voltage ranges without the necessity of much vacuum-tube amplification. Neutron counters are made using BF_3 gas, the B^{10} (n, α) Li^7 reaction producing the alpha-particle which is detected by the proportional counting procedure described. Flights have been made with instruments carried by small balloons and using single Geiger counters. The data were transmitted from the balloon to the ground station by automatic short wave radio. Such flights show no diurnal effect in the cosmic radiation at great elevations ($\frac{1}{2}$ meter of water) as large as four per cent. of the total cosmic-ray intensity. Further, the flights show that no increase in the ionization as great as two per cent. of that due to the cosmic-ray intensity takes place at an altitude of 20 km., which can be correlated with a solar flare, although this same flare produced abundant ionization below 80 km. and caused a radio fade-out. The absorption coefficients for the flare radiation are calculated. Flights were made with neutron counters and the radio-balloon method, which yielded measurements of the neutron intensity as a function of elevation. It is found that the neutrons increase rapidly with elevation, the rate of increase being faster than that of the total intensity of the cosmic radiation, and approximately equal to that of the big bursts. The production of neutrons in the atmosphere by the cosmic radiation is discussed, and a production cross section of 10^{-25} sq. cm. is computed.

THE BEHAVIOR OF HIGH ENERGY ELECTRONS IN THE COSMIC RADIATION.*

BY

C. G. MONTGOMERY AND D. D. MONTGOMERY.

The behavior of electrons and photons of high energy is discussed in relation to the production of large bursts of

* An abstract of an article published in full in *Reviews of Modern Physics*, 11, 255 (1939).

cosmic-ray ionization, or Hoffmann *Stösse*, and the occurrence of nuclear "vaporizations." It is shown that the electrons from the disintegration of mesotrons have an importance equal to that of the cascade electrons. The number and size-frequency distribution of large showers (of a hundred or more rays) from thin and thick pieces of lead at sea level, and the variation with elevation of such showers are well accounted for by the action of electrons and photons from these two sources. It is unnecessary to invoke the direct production of bursts by penetrating rays by means of an explosion process. The behavior of showers of a few rays is likewise well accounted for. However, difficulties are encountered in explaining: (*a*) the relative numbers of bursts from large thicknesses of iron and lead, and (*b*) the occurrence of showers, from the air, which have a large number of rays per unit area. The hypothesis is advanced that the showers of heavily ionizing particles, or nuclear vaporizations, are produced by electrons and photons in the same range of energy as those which produce the large bursts. The identification of showers of heavily ionizing particles with Hoffmann *Stösse* is shown to be untenable. A determination of the absolute number of neutrons in the cosmic radiation at sea level is shown to be consistent with the supposition that these neutrons are produced in the nuclear vaporization process.

DISCUSSION OF "THE BEHAVIOR OF HIGH ENERGY ELECTRONS IN THE COSMIC RADIATION."*

BY

C. G. MONTGOMERY AND D. D. MONTGOMERY.

In the discussion of our paper, Professor Bethe pointed out that it is unjustified to utilize the value of the neutron flux, as we have calculated it, to make the statement that there is one neutron of thermal energy for every sixteen

* This discussion is reprinted from the *Reviews of Modern Physics*, 11, 266 (1939). It refers to a paper having the above title, written by the same authors and published in full in the *Reviews of Modern Physics*, 11, 255 (1939).

ionizing cosmic rays. To determine the number of neutrons per cosmic ray it is necessary to know the energy distribution of neutrons in equilibrium with nitrogen. With the picture of copious scattering in mind, we have tacitly assumed this distribution to be essentially Maxwellian without further calculations to ensure that this was the case. We are grateful to Professor Bethe for calling our attention to this point.

However, our final value for the rate of production of neutrons by cosmic rays is completely independent of these considerations, as is easily seen. Confining our attention to any group of neutrons within the velocity range dv at the velocity v, and calling dF the flow per square centimeter for such neutrons, we have

$$dR_a = a\sigma_a dF, \quad \text{and} \quad dR_r = b\sigma_r dF,$$

where dR_a is the rate of absorption from the group in air, dR_r is the rate of recording of neutrons by the ionization chamber, σ_a is the cross section for capture in air, σ_r is the cross section for capture by the boron trifluoride, while a and b are absolute constants.

Now σ_a and σ_r are functions of the velocity. Provided, however, that they are the same function of the velocity, as indeed they are, since each is proportional to $(1/v)$, we have $dR_r = AdR_a$. This may be integrated, regardless of the dependence of dR_r and dR_a upon v, to the form $R_r = AR_a$. This represents the rate of absorption per cc. of neutrons in the atmosphere, and so the rate of production of neutrons per cc., in terms of the rate of capture by the boron trifluoride, in a form absolutely independent of the velocity distribution. In other words, the velocity feature implicitly inherent in the cross section $\sigma = 3 \times 10^{-21}$ cm.^{2}, assumed for thermal neutrons in our calculations above for the capture of neutrons in our recording apparatus, becomes canceled, as regards the ultimate determination of the rate of production of neutrons in air, by the utilization of the cross section for capture of thermal neutrons by nitrogen which involves the same velocity factors.

EVIDENCE THAT PROTONS ARE THE PRIMARY PARTICLES OF THE HARD COMPONENT.*

BY

THOMAS H. JOHNSON.

Experimental and theoretical investigations seem to have established the following facts with reasonable certainty: (1) The cosmic radiation in the atmosphere consists of two components, the hard and the soft. (2) The primary particles which produce the soft component are electrons whose behavior in the atmosphere is described by the multiplicative theory. (3) The hard component is secondary to some other form of primary radiation and it consists of particles of intermediate mass called mesotrons. (4) The soft component accounts for most of the observed intensity in the upper atmosphere but the hard component predominates at sea level and below.

For a complete interpretation of the cosmic radiation it is still necessary to make some statement regarding the nature of the primary particles which produce the mesotrons of the hard component, and for this purpose there already exists some experimental evidence. In the first place it is known that those primary mesotron-producing rays whose energies lie within the field-sensitive range are almost entirely positive. This conclusion is reached by making a quantitative comparison of the east-west asymmetry which measures the excess of positive over negative primaries with the latitude effect which measures the total charged component. Although this analysis refers to the total field-sensitive intensity at sea level there is little doubt that the hard component alone is involved, since practically no field-sensitive soft component rays reach sea level.

The second point bearing upon our problem is that the soft component primaries seem to be equally positive and negative and therefore distinct from the primaries of the hard component. The first evidence of this fact was found in a study of the E.-W. asymmetry of showers at mountain top elevations within the equatorial zone.

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* Condensed from a paper published in *Reviews of Modern Physics*, 11, 208 (1939).

What is probably a more convincing experiment leading to this same conclusion was recently carried out in Panama by the writer in collaboration with J. G. Barry. In this work the asymmetry of the total radiation was studied at very high elevations with instruments carried by free balloons. Four flights in which the average intensities from the eastern and western halves of the sky at 60° from the zenith were compared showed that the western intensity was only about seven per cent. greater than the eastern intensity, whereas if all of the primaries of the soft component had been positive an asymmetry of sixty per cent. would have been expected. There seems to be no appreciable correction to be applied to our results because of scattering or magnetic deflections in the earth's field and we are left with the conclusion *that the soft component is produced by primary electrons whose signs of charge are almost equally divided between positive and negative.* Since the mesotrons are produced by predominantly positive primary particles these cannot be the electrons of the soft component but they must consist of some other form of primary particle. The instability of the mesotron excludes the possibility that secondary mesotrons are produced by other primary mesotrons and we are left with protons or other heavier nuclear particles as the only reasonable possibility.

The position of the knee of the latitude effect is also in opposition to the assumption that mesotrons are produced by electrons, and it agrees better with the assumption that the mesotrons are produced by protons. The knee occurs at 40° latitude where the critical energy for electrons is 7.5 Bev. On the other hand the energy required for a mesotron to pass through the atmosphere is only about 2 Bev if the known ionization losses are taken into account. If the mesotrons were produced by electrons some of them should acquire the full energy and the knee of the latitude effect would be expected to occur above 50° latitude. On the other hand if protons are the primary mesotron-producers their critical energy for 40° latitude is 6.4 Bev and the maximum energy which a proton of that energy could impart to a mesotron in a head-on collision is only 3.1 Bev. The energy lost by a mesotron in passing through the atmosphere might be brought

into agreement with this value if all types of energy losses were taken into account.

Experiments by Montgomery, Montgomery, Ramsey and Swann have indicated that not more than five per cent. of the rays at sea level can be primary protons and similar upper limits to the proton intensity have been established by cloud-chamber analyses. An absence of protons to this extent, however, cannot be taken as an objection to the assumption of primary protons for these would probably be prevented from reaching sea level because of nuclear absorption. A cross section of the order of πr_0^2 (the Thompson cross section) is equivalent to an absorption coefficient of 1.0 per meter of water or to a probability of 1 : 25,000 that a ray will reach sea level. Absorption coefficients of this order have been found for rays producing large bursts, nuclear evaporations, and neutrons and it is possible that some of these phenomena could also be ascribed to primary protons.

As a final argument for the existence of primary protons it may be shown on the basis of very general and plausible assumptions regarding the electrical potentials in the space surrounding the source of cosmic rays that protons with high energy could be generated, regardless of whether the initial energy was acquired by electrons or protons.

SHOWERS PRODUCED BY PENETRATING RAYS AND ALLIED PHENOMENA.*

PART ONE. AN APPARATUS FOR RECORDING SHOWERS PRODUCED BY PENETRATING RAYS.

BY

W. F. G. SWANN.

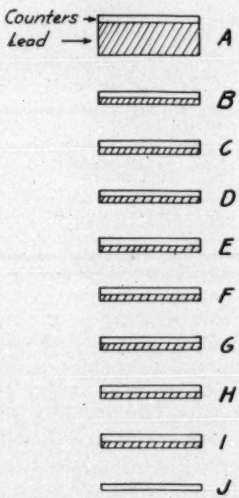
In its complete form and in its essentials, the apparatus which was devised by Mr. W. E. Ramsey and the writer comprises the following parts, Fig. 1:

First there are eight slabs of lead, shown cross-hatched, each 1 cm. thick. Above each slab, as shown in *B*, *C*, *D*, *E*,

* Condensed from a paper published in full in *Reviews of Modern Physics*, 11, 242 (1939).

F, G, H, I, is an array of Geiger-Müller counters. Each counter is 20 cm. long and 1 cm. in diameter. The counters are packed in trays, each tray forming a plane of counters with their axes parallel. Thus, a whole tray constitutes a square sensitive area, 400 square centimeters in size. Above this assembly is placed a slab of lead 18 cm. thick, and on the top of this is placed an additional counter tray, *A*, similar to the others and still another tray, *J*, is placed below all of the slabs of lead, as shown in Fig. 1. Counting from the top

FIG. 1.



Arrangement of counters and slabs of lead.

downwards, the successive counter trays are arranged with their counters alternately in perpendicular directions.

Every counter is connected to an individual electroscope, so that in all there are 180 such electroscopes. Each electroscope carries a mirror, and by means of a suitably designed

optical system each mirror is caused to shine a spot of light upon a ground glass screen, so that in principle we have ten parallel rows of spots.

Now, the electrical circuits associated with the counters are so arranged that none of these electroscopes are permitted to operate unless at least one counter in each tray discharges simultaneously. The control thus provided insures that any electroscope deflection recorded is associated directly or indirectly with a ray which has passed through all nine slabs of lead, and which may thus be regarded, in general, as a penetrating ray. However, when the simultaneous discharge of one or more counters in each tray permits the apparatus to operate, the deflections of the electroscope spots which result provide a complete record of all that has happened as regards shower production in the various slabs of lead initiated by the passage of the penetrating ray.

CORRELATION OF THE EXPERIMENTS WITH THE THEORY OF SHOWER PRODUCTION.

H. J. Bhabha [1] has developed a theory of shower production by mesotrons, according to which he calculates the number of cases in which, in the equilibrium condition in lead, a mesotron is accompanied by one electron, two electrons, or, in general, n electrons. E is the energy of the mesotron and m the rest mass. The numbers in question are given for a 100-electron mass mesotron, except for the case $E - mc^2 = 10^8$ where they are given for a 10-electron mass mesotron. They do not vary very drastically with the energy of the mesotrons over the range 10^8 to 10^{12} for the quantity $E - mc^2$. The theoretical data are, in fact, digested under "Theoretical" in Table I, the value for $n = 3$ being interpolated from Bhabha's data. However, the numbers given represent the calculated number of cases in which, in 570 pictures (taken as our standard number of observations for comparison) we should expect a mesotron to be accompanied by one ray, two rays, $\cdots n$ rays. The numbers are for electrons of energy greater than 10^7 ev., the critical energy for lead. If energies below this are considered, the numbers should be doubled. Many of

[1] H. J. Bhabha, *Proc. Roy. Soc.*, **164**, 257 (1938).

the electrons below 10^7 ev. would, however, not record in our counters.

Below the theoretical values are contained our experimental results, obtained on observations below the 18-cm. block of lead and also on observations below the additional 1-cm. pieces of lead. The individual numbers of rays in any one picture, below the 18-cm. block are in general quite different to those below the additional slabs; but in view of the fact that equilibrium may be supposed to have been attained in 18 cm. of lead, we should expect the averaged results for the two cases to be in harmony, as indeed they are within the limits of accuracy of the experiments, when one takes into account the large statistical fluctuations to be expected in the case of the smaller numbers.

TABLE I.

Comparison of Theory of Shower Production with Experimental Results. Number of Cases out of 570 in Which We Would Expect One Mesotron of Given Energy Specification to be Accompanied by n Rays.

ENERGY SPECIFICATION.		$n=1$	2	3	4	5	6	7	8
		THEORETICAL.							
	$E-mc^2=10^8$ ev.	13.6	2.3	1.5	0.8	—	—	—	—
	10^{10}	26.0	8.0	5.6	3.2	2.1	0.7	—	—
	10^{12}	26.0	8.5	6.0	3.4	2.3	0.8	—	—
		EXPERIMENTAL.							
Exp. 1	Below 18 cm. Pb	11	5	1	2	1	1	1	1
	Below 19 cm. Pb	13	4	3	0	3	0	0	0
Exp. 2	Below 18 cm. Pb	7	3	0	0	0	1		
	Below 19 cm. Pb	10	4	1	1	0	0		
	Below 20 cm. Pb	12	2	1	0	0	0		
	Below 21 cm. Pb	11	2	1	1	0	0		
	Below 22 cm. Pb	9	1	0	1	0	0		
Averages for all data		10	3	1	0.7	0.6	0.3		
Corrected averages		12.5	5	2	1.7	1.8	1.2		

The procedure adopted in obtaining these experimental results was to confine interest to those cases where (*a*) there was only one ray recorded in each tray, (*b*) a single ray through both upper trays with a multiplication for trays 3 or 4 or both, (*c*) cases where there were two counter discharges in the upper tray with multiplication below, and where the evidence

was in favor of the assumption that the two entering rays were in actuality penetrating rays which passed right through the apparatus. There were only about five of these cases in all.

The average for all the cases, corrected for inefficiency of counters, is given in the next to the last row of Table I, and as regards order of magnitude it is, at any rate, in agreement with the theoretical values for energies within the range considered.

EVIDENCE FOR MESOTRONS IN SHOWERS.

When there is perpetuation of two or more simultaneous rays through one or more blocks of lead of thickness 1 cm., without multiplication, the evidence is in favor of the rays being mesotrons. In about 1100 pictures there were 5 cases where a single ray entering the 18-cm. block of lead emerged as two rays which passed through one or more centimeters of lead without multiplication.

SHOWERS PRODUCED BY PENETRATING RAYS AND ALLIED PHENOMENA.*

PART TWO. CERTAIN CONSIDERATIONS PERTAINING TO COSMIC-RAY PHENOMENA IN THE STRATOSPHERE.

BY

W. F. G. SWANN.

It was found that in the stratosphere flight of *Explorer I*, at an atmospheric depth the equivalent of 2 meters of water, the horizontal intensity formed 25 per cent. of the vertical. In the Piccard flight at a water equivalent depth of 1 meter the horizontal intensity was 50 per cent. of the vertical, and in the flight of *Explorer II* at a water equivalent depth of 0.5 meter the horizontal intensity was 80 per cent. of the vertical.

We can account for the uniformity of intensity in all directions in the stratosphere if we assume that there is a

* Condensed from a paper published in full in *Reviews of Modern Physics*, 11, 242 (1939).

component of the incoming radiation which becomes absorbed in the higher regions of the atmosphere and produces, possibly after a certain time delay, secondary bursts of radiation which are symmetrical in all directions.

Theoretical considerations prevent its being a matter of great ease to realize a condition in which secondary bursts of rays occur in such fashion that the rays travel out from a center more or less symmetrically in all directions. In the case where the particles concerned have velocities comparable with that of light, the laws of conservation of energy and momentum conspire to insure in the secondary particles a strong perpetuation of the direction of the primary particles. However, if we invoke an intermediate stage in which particles of velocity considerably less than that of light are formed, but with a rest mass sufficient to provide, on disintegration, for lighter particles with velocities comparable with that of light, we can provide an explanation of the phenomenon. Thus, to consider a specific possibility, suppose that a primary particle should enter our atmosphere and give rise to mesotrons on collision with the atoms of the air. If some of these mesotrons have velocities appreciably different from that of light, it is permissible for them to travel in directions quite different from that of the primary particle, or even to be born at rest. We are, in fact, not interested in the actual velocity of these particles or of their directions. Regarding some of these particles as approximately at rest, we realize that with a mean life of only 10^{-6} of a second, they could not travel more than 300 meters on the average without disintegrating, even if they traveled with the velocity of light, and indeed we are assuming that they travel with a smaller velocity than that of light. When a mesotron disintegrates, it shoots out an electron and a neutrino. Since we are assuming the mesotrons to be at rest, the electrons will come out on the average in random directions, so that the intensity, insofar as it results from this contribution, should tend to equality in all directions in the stratosphere and, indeed, there should be an appreciable intensity in upward directions from below.

As we descend from the higher regions of the stratosphere, we may expect to find the homogeneity of the radiation in all directions become diminished because the mesotrons which

reach to these levels are those which have lived long enough to do so. In other words, since mesotron life increases with kinetic energy, these mesotrons must be those of velocity comparable with that of light. In the system of axes moving with one of these mesotrons, the disintegration of the mesotron may occur with equal probability in any direction, but when we transfer this story to fixed axes we find a favoring of the forward direction for the electron emission, which fact represents simply another aspect of the conservation of energy and momentum considerations already referred to. Thus, as we descend through the stratosphere into the lower regions of the atmosphere, we may expect the symmetry of emission to diminish, until finally we approximate to the intensity-zenith angle curves found at low altitudes. In other words, the conclusions are in harmony with our experimental findings.

If we accept this process, we are faced with a strange situation as regards the ordinarily accepted origin of the soft component through the supposition of entering primary electrons with subsequent initiation of the cascade process. For the cascade process provides primarily for perpetuation of direction of the primaries, apart from magnetic field considerations, and there is thus no room for it as an agency superposed upon a theory which provides for symmetry in all directions if we seek to account for a resulting situation in which there is practically a quality of intensity for all zenith angles from zero to 90°.

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NOTES FROM THE BIOCHEMICAL RESEARCH FOUNDATION.

An Agent, Isolated from a Soil Bacillus, Which Inhibits Encapsulation of Friedländer's Bacterium and Is Highly Bactericidal for Gram-positive Microörganisms.—J. C. HOOGERHEIDE. During the course of a study on capsule formation of pathogenic bacteria, an organism was isolated from soil, which, when growing on liquid media, releases a soluble agent capable of preventing Friedländer's bacterium (Type A and B) from forming capsules.

The preparation, in a crude form, of a cell-free solution of the principle responsible for this inhibition from cultures of this soil bacillus already has been reported elsewhere (*Journal of Bacteriology*, 1940—in press).

Considerable progress can be reported now towards further purification and identification of this active agent. Furthermore, it has been found that the crude as well as the purified active principle, in addition to its effect on encapsulation, has another important property, namely that it is highly bactericidal for all Gram-positive microörganisms so far tested.

Isolation and Purification of the Active Agent.—A cell-free solution of the active principle inhibiting encapsulation of Friedländer's bacterium was obtained (as has been reported) from the broth by precipitation upon addition of electrolytes and redissolving in water, or by disruption of the cells of the soil bacillus by sonic vibration with a supersonic oscillator.

In order to purify and concentrate the active agent in these crude colloidal solutions, ethanol was added in increasing amounts, in order to obtain a fractional precipitation. Precipitates were formed, but they were all inactive, whereas the activity remained quantitatively and unaltered in the supernatant fluid. Even when the alcohol concentration was increased to as high as 95% the active agent was still in solution. This property of alcohol solubility greatly facilitated the isolation of the active agent; products of a much higher degree of purity were obtained.

To a seven day old culture of the soil bacillus in broth, there were added 2 to 5 per cent. of electrolyte and HCl until a pH of 4.0 was attained. The culture was then allowed to stand overnight after which bacterial debris and precipitate was centrifuged and the supernatant liquid discarded. The residue was then extracted with 95 per cent. alcohol until no more turbidity could be observed after dilution with an equal volume of water. The combined alcoholic extracts were then evaporated to dryness and, since the active principle appeared to be insoluble in ether, petroleum ether and benzol, the residue was thoroughly extracted with these solvents. The extractions removed a considerable part of waxy, inactive impurities. The residue was then dissolved in absolute alcohol and the insoluble, inactive fraction discarded. The concentrated alcoholic solution was dialyzed for 24 hours against running tap-water and another 24 hours against distilled water. The active agent partly precipitates, partly forms a colloidal solution in the dialyzing bag. Upon evaporation of the water a highly active, greyish white powder was obtained. From 100 liters of culture medium, 15 grams of purified active principle were obtained.

An amount as small as 0.004 mgm. added to one cc. of culture medium markedly inhibited encapsulation of Friedländer's bacterium.

Properties.—Besides being soluble in alcohol the active principle is readily soluble in acetone, ethylacetate, dioxane, chloroform, pyridine and glacial acetic acid. However, it was observed that traces of water in these solvents greatly increased the solubility. This is particularly true for acetone, ethylacetate and chloroform in which solubility is very restricted when absolutely dry. The active principle is insoluble in ether, petroleum ether, benzol and carbon tetrachloride. Upon addition of water to a concentrated alcoholic solution, a colloidal solution can be obtained which is very stable and may be stored for months without any appreciable loss of activity. The concentration of such a colloidal solution can be as high as 1 mgm. per cc.; higher concentrations tend to precipitate, especially in the presence of electrolyte or upon heating. The active principle is heat stable and can be dried for 24 hours at 100° C. without loss of activity.

The absorption spectrum in ultra-violet light shows a distinct maximum at about 2800 Å, a second maximum at 2900 Å, and shows a minimum at about 2500 Å. The absorption spectrum closely resembles that of tryptophane.[1] This may be no mere coincidence since tryptophane seems to be one of the components of the molecule.

An alcoholic solution of the active principle gave a positive biuret reaction (with 0.3 mgm. dissolved in 0.3 cc.), a positive xanthoproteic reaction (with 0.1 mgm. dissolved in 0.1 cc.) but a negative ninhydrin reaction. The reactions of Voisinet and of Adamkiewicz, both protein reactions based on the presence of tryptophane in the molecule, were positive.

Though these reactions indicate the presence of a protein, no digestion could be obtained upon addition of proteolytic enzymes such as trypsin, papain and bacterial protease; however, upon addition of solutions of these enzymes the active agent precipitates. Erepsin, too, does not split the active agent. Several samples of the active material were found to contain 12.5 per cent. nitrogen, but no sulfur could be detected. Less than 0.5 per cent. ash was found.[1]

Work is now in progress towards crystallization of the active principle.

Bactericidal Effect.—When tested for its ability to inhibit encapsulation of pneumococci, it was found that the agent was extremely toxic for pneumococci. An amount as low as 0.0005 mgm. added to one cc. of broth would completely prevent growth of the pneumococcus. This, of course, was in great contrast to what had been observed with Friedländer's bacterium, where addition of even large amounts of the agent would not in the least interfere with growth; only prevention of encapsulation was observed.

Upon further investigation, it was found that the agent not only was toxic for pneumococci, but also for all species of Gram-positive bacteria so far tested (*Str. haemolyticus, Str. mastitides, Str. faecalis, Gaffkya tetragena, Staph. aureus, Bac. anthrax, Cl. sporogenes, Cl. histolyticum* and *Cl. Welchii*). In this regard the active principle, isolated by us primarily as an inhibitor of encapsulation, seems to have activities similar

[1] Absorption spectra were determined by Miss R. Franklin and the chemical analysis was made by the microchemical department of these laboratories.

to an agent recently isolated by Dubos from a bacillus isolated from a soil sample to which suspensions of Gram-positive microörganisms had been added over a period of two years. Our active principle, on the other hand, can be prepared from several strains of soil bacteria (we isolated 4 strains from 10 different soil samples) without any pretreatment of the soil and without any adaptation of the organism in the soil to digestion of Gram-positive organisms.

When a colloidal solution of our active principle is added to a full grown culture of pneumococci or other Gram-positive microörganisms a complete sterilization occurs within a few hours.

Growth curves obtained in the presence of minute amounts of the active principle indicate that growth is not retarded as is usually the case in the presence of growth inhibitors. Apparently part of the inoculum is rapidly killed and the remainder of the inoculum shows the normal growth curve, typical for this reduced amount of inoculum (a prolonged lag period). The lag period is longer the more inoculum is killed. When sufficient active principle is added to kill the whole inoculum, no growth occurs, even after prolonged incubation. Either a full grown culture or no growth at all is obtained.

Intraperitoneal injection of a mixture of 0.02 mgm. of the active principle and 1,000,000 lethal doses of virulent pneumococci protected mice against infection.[2] The same was found to be true for a simultaneous injection of the active principle and a thousand times lethal dose of Bac. anthrax in mice.

Experiments to test the therapeutic value of the active principle are in progress and will be published shortly.

Preliminary studies, carried out by Dr. V. Murray Wright, on its therapeutic effect on badly infected wounds, by applying dressings soaked with solutions of the active principle, are in progress and give very promising results.

Effect of Solvation on Frictional Constants and Frictional Ratios as Determined with the Ultracentrifuge and by Diffusion.—E. O. KRAEMER. When a solution of a macromolecu-

[2] The animal testing was done by Louis Smith.

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lar substance is centrifuged, the centrifugal force on one mole or N molecules of the macromolecular material is equal to the product of Avogadro's constant N, the effective mass of a single molecule, and the centrifugal acceleration $\omega^2 x$, or is equal to the product of the volume of the N molecules, the difference in density of the molecules and the solution, and $\omega^2 x$. If the macromolecule is "solvated" (using the term in a more general sense than usual) by combining with r_i grams of component i of the solvent per gram of macromolcular substance, the molecular weight M_c of the sedimenting particles is $M_1(1 + \Sigma r_i)$ and their partial specific volume V_c is $(V_1 + \Sigma r_i V_i)/(1 + \Sigma r_i)$ where M_1 and V_1 are respectively the molecular weight and the partial specific volume of the free or uncombined macromolecules. (Cf. previous notes in this journal, J. FRANK. INST., **229**: 393, 1940; *ibid.*, **229**: 531, 1940; as well as the corresponding discussion of the sedimentation of particles in general by Svedberg and Pedersen, "The Ultracentrifuge," Oxford University Press, London, 1940). The difference in the densities of solvated particles and solution is

$$\rho_p - \rho = \frac{1 - V_c\rho}{V_c} = \frac{(1 - V_c\rho) + \Sigma r_i(1 - V_i\rho)}{V_1 + \Sigma r_i V_i}.$$

Therefore the centrifugal force C.F. for one mole of the solvated molecules is given by the expression

$$(1) \quad \text{C.F.} = M_c V_c \left(\frac{1 - V_c\rho}{V_c}\right)\omega^2 x$$
$$= M_1[(1 - V_1\rho) + \Sigma r_i(1 - V_i\rho)]\cdot\omega^2 x.$$

The frictional force F.F. exerted by the medium of viscosity η upon the motion of N particles or one mole of the solvated macromolecular substance is equal to the product of the frictional coefficient f and the velocity dx/dt, or is equal to the product of the viscosity, the frictional factor per mole F, and the velocity, where F is a function solely of molecular shape parameters S and of the molar volume. That is,

$$(2) \quad \text{F.F.} = f dx/dt = \eta F dx/dt \qquad \text{where} \qquad F = \phi(M_c V_c, S).$$

For steady motion, the centrifugal and frictional forces are equal; therefore equations (1) and (2) may be combined

and solved for $\frac{dx/dt}{\omega^2 x}$ (which equals s_c, the sedimentation constant as defined by Svedberg) or for F_c, the subscript c distinguishing quantities for the solvated molecule.

$$(3) \quad s_c = \frac{M_c(1 - V_c\rho)}{\eta F_c} = \frac{M_c(1 - V_c\rho)}{f_c}$$

$$\text{and} \qquad F_c = \frac{M_c(1 - V_c\rho)}{\eta s_c}.$$

Multiplying the expression for F_c by $1/N$, $1/M_c$, or $1/M_cV_c$ gives respectively the friction factor per molecule, per gram, and per cubic centimeter. The frictional factor per gram is the reciprocal of what Lamm (*Kolloid Ztschr.*, **69**: 44, 1934) calls the "specific mobility." Since friction, whether it is in connection with sedimentation or diffusion, is essentially a volume effect, the frictional factor per cubic centimeter, F/MV, is of special significance, and is equal (by definition) to the reciprocal of the "intrinsic sedimentation constant" $[s]$. Thus

$$(4) \qquad \frac{F_c}{M_cV_c} = \frac{(1 - V_c\rho)}{V_c\eta s_c} = \frac{1}{[s_c]}.$$

The "intrinsic sedimentation constant" represents the sedimentation constant reduced to unit centrifugal acceleration, unit viscosity, and unit density difference, and is therefore dependent only on the dimensions of the sedimenting particle. If $[s]$ or F for a given substance is found to vary with change in solvent, temperature or centrifuging conditions, it is a definite indication that the molecule or particle is changing in one or more of the qualities: shape, aggregation, and degree of solvation.

Introduction of the values of M_c and V_c into equations (3) and (4) gives the expressions relating s_c, $[s_c]$, f_c, and F_c for the solvated material to the molecular weight and partial specific volume of the "unsolvated" macromolecule and the degree of solvation described by the values of r_i; that is

$$(5) \quad s_c = \frac{M_1[(1 - V_1\rho) + \Sigma r_i(1 - V_i\rho)]}{\eta F_c}$$

$$\text{and} \qquad f_c = \eta F_c = \frac{M_1[(1 - V_1\rho) + \Sigma r_i(1 - V_i\rho)]}{s_c}$$

and from equation (4), since $F_e = \frac{\mathbf{RT}}{\eta D}$

$$(6)\quad [s_e] = \frac{M_1(V_1 + \Sigma r_i V_i)}{F_e} = \frac{M_1(V_1 + \Sigma r_i V_i)\eta D}{\mathbf{RT}} = \frac{\eta s_e(V_1 + \Sigma r_i V_i)}{[(1 - V_1\rho) + \Sigma r_i(1 - V_i\rho)]}.$$

In each case, when r_i is set equal to zero, the expressions reduce to those for unsolvated molecules.

For the special case of a spherical molecule, $F = N6\pi R$, where R is the radius of the molecule and is equal to $\left[\frac{3MV}{4\pi N}\right]^{1/3}$; so in terms of molecular volume $M_e V_e$,

$$(7)\quad F_e = N6\pi\left[\frac{3M_eV_e}{4\pi N}\right]^{1/3} = k(M_eV_e)^{1/3} = k[M_1(V_1 + \Sigma r_i V_i)]^{1/3}.$$

Substituting this value of F into equations (5) and (6) gives the corresponding values for *spherical* solvated molecules. Thus equation (5) becomes

$$(8)\quad s_e = \frac{M_1[(1 - V_1\rho) + \Sigma r_i(1 - V_i\rho)]}{\eta k[M_1(V_1 + \Sigma r_i V_i)]^{1/3}} \qquad \text{and} \qquad f_e = \eta F_e = \eta k[M_1(V_1 + \Sigma r_i V_i)]^{1/3}$$

and equation (6) becomes

$$(9)\quad [s_e] = \frac{M_1(V_1 + \Sigma r_i V_i)}{k[M_1(V_1 + \Sigma r_i V_i)]^{1/3}} = 1/k \cdot [M_1(V_1 + \Sigma r_i V_i)]^{2/3}.$$

Considering equation (8) for f_e, when the values of r_i are positive and zero, we see that the molar frictional coefficient is increased by solvation in the degree expressed by the ratio

$$(10)\qquad f_e/f_0 = \left(\frac{V_1 + \Sigma r_i V_i}{V_1}\right)^{1/3},$$

where f_e and f_0 are the frictional coefficients of the spherical solvated, and of the spherical unsolvated macromolecule. However, if the frictional ratio f/f_0 is calculated in the usual

way from an experimental value of s, using the values M_1 and V_1 for the unsolvated molecule (as must be done in the absence of quantitative data on solvation), the value of f/f_0 so obtained is not that expressed by equation (10) owing to the fact that solvation affects the centrifugal force on the sedimenting material as well as the frictional coefficient. The frictional constant f calculated in such a case is given by the equation $f = \frac{M_1(1 - V_1\rho)}{s}$ where s is determined by equation (8); that is

$$(11) \qquad f = \frac{(1 - V_1\rho)\eta k[M_1(V_1 + \Sigma r_i V_i)]^{1/3}}{[(1 - V_1\rho) + \Sigma r_i(1 - V_i\rho)]}.$$

The corresponding value of f_0 for the spherical unsolvated molecule is $f_0 = \eta k(M_1 V_1)^{1/3}$ and f/f_0 comes out to be

$$(12) \quad f/f_0 = \frac{(1 - V_1\rho)}{[(1 - V_1\rho) + \Sigma r_i(1 - V_i\rho)]} \cdot \left(\frac{V_1 + \Sigma r_i V_i}{V_1}\right)^{1/3}.$$

For a binary solution, the first term in this equation may be expressed in terms of the weight-fraction concentration w_1 of the unsolvated material (see the previous note where the same term occurs in other quantities), and, accordingly,

$$(13) \qquad f/f_0 = \frac{1 - w_1}{1 - w_1 - rw_1}\left(\frac{V_1 + rV_0}{V_1}\right)^{1/3},$$

where V_0 is the partial specific volume of the solvent.

Since the kinetic force active in diffusion (unlike centrifugal force) is not affected by solvation, the frictional ratio for diffusion, calculated in the usual way, is equal to f_e/f_0, the ratio of the frictional coefficients of solvated and unsolvated molecules, as given by equation (10). In case the macromolecule is known to be spherical, we may thus determine from diffusion experiments the molecular volume $M_e V_e$ ($= M_1[V_1 + \Sigma r_i V_i]$) of the solvated macromolecule, for

$$(14) \qquad f = \frac{\mathbf{RT}}{D} = \eta k[M_1(V_1 + \Sigma r_i V_i)],$$

but unless the solution is a binary one, we can not thus determine r or the molecular weight $M_1(1 + \Sigma r_i)$ of the solvated macromolecule.

The difference in the frictional ratios calculated from sedimentation constant and from diffusion for a solvated macromolecule might at first sight appear to contradict the usual assumption that the frictions for sedimentation and diffusion are the same, as expressed in the familiar equation

$$M_1 = \frac{\mathbf{RT}s}{D(1 - V_1\rho)} .$$

Such is not the case, and, as a matter of a fact, the above considerations are definitely based upon the assumption that in a given medium the frictional factor of any kind of particle, whether non-spherical or solvated, is actually the same for both sedimentation and diffusion. The difference in the calculated frictional ratios is due to the fact that the true value f_c of the frictional coefficient of a solvated molecule can not be calculated from the sedimentation constant without knowing the degree of solvation r, or the partial specific volume, or the molecular weight of the solvated macromolecule. Comparison of equation (12) with the equation expressing the error in molecular weights due to solvation (see equation (9) of the previous note, J. FRANK. INST., **229**: 531, 1940) shows that the calculated value of the frictional ratio is related to the ratio of the actual frictional coefficients for solvated and unsolvated molecules f_c/f_0 by the same factor that expresses the error in molecular weights when solvation occurs. In both cases, for binary solutions, true values are obtained by extraplation to zero concentration of macromolecular substance. For multicomponent solutions, the ratio of actual frictional coefficients f_c/f_0 for a solvated molecule can not be calculated from the sedimentation constant without knowledge of the degree of solvation, although in even this case it may be calculated from the diffusion constant D. Owing to the difference in f/f_0 for sedimentation and diffusion, it is desirable to use symbols which indicate the experimental basis of the factor, e.g., f_s/f_0 for the former, f_D/f_0 for the latter.

In Table I are shown some numerical examples to illustrate the significance of solvation on frictional ratios for some particular cases of spherical molecules combining only with water of the solution.

TABLE I.

Illustrative Examples of Effect of Solvation on Frictional Coefficients and Frictional Ratios of Spherical Molecules.

$V_1 = 0.750$ (e.g., protein). $V_0 = 1.002$ (e.g., water).
V = specific volume of solution.

			f_s/f_0							
r	$\frac{V_1+rV_0}{V_1} = (f_e/f_0)^3$	$\frac{f_D/f_0}{(=f_e/f_0)}$	Binary Soln. $w_1=0.01$	$V=V_1$	$V=\frac{V_1+rV_0}{1+r}$	$V=V_0$	$V<V_0$ $(=0.70)$	$\frac{V_1}{<V<}\frac{}{\frac{V_1+rV_0}{1+r}}$	$V=0.85$	$V=0.991$
0	1.00	1.00	1.00	0/0	—	Same as f_D/f_0	1.00	Always negative	1.00	1.00
0.25	1.33	1.10	1.10	0	$\pm\infty$		0.44		1.78	1.11
0.50	1.67	1.19	1.19	0	$\pm\infty$		0.30		4.96	1.22
1.0	2.34	1.33	1.34	0	$\pm\infty$		0.19		−2.56	1.39
2.0	3.67	1.54	1.57	0	$\pm\infty$		0.12		−0.76	1.69
4.0	6.35	1.85	1.93	0	$\pm\infty$		0.07		−0.36	2.26

As may be seen from equation (12) and Table I, f_D/f_0 is always greater than unity when solvation occurs without change in molecular shape (except for the rare occasion when solvation occurs with a component of negative partial specific volume). The same is true for f_s/f_0 in binary solutions, but in multicomponent solutions, f_s/f_0 may have values between $-\infty$ and $+\infty$, depending upon the specific volume of the solution. When $V = V_1$, f_s/f_0 is zero although sedimentation occurs "upwards" (the density of the solvated molecule being less than that of the solution). When $V = (V_1 + rV_0)/1 + r$, no sedimentation occurs and f_s/f_0 is $\pm\infty$, representing a discontinuity in the relation of f_s/f_0 vs. r or V. When V is less than V_1, f_s/f_0 is positive but less than unity. When V is greater than V_1 and less than $(V_1 + rV_0)/1 + r$, f_s/f_0 is always negative since sedimentation of the solvated and unsolvated molecules would be in opposite directions. When V approaches V_1, moderate degrees of solvation give rise to very large values of f_s/f_0. It would therefore be necessary in applying McBain's proposed method for determining V_e in the ultracentrifuge to rely largely on diffusion and f_D/f_0 values (rather than on f_s/f_0) as a control of the effect of the changes in solvent composition on degree of solvation and state of aggregation of the macromolecule. As will be shown in a subsequent note,

viscosity measurements would provide an additional sensitive correlative control.

The last column of the table represents conditions in typical protein solutions as they are used in most ultracentrifuge investigations, namely a 1 per cent. protein solution in 0.2 molar sodium chloride (this is the same example as was used in the previous note). For such a solution, the difference between f_s/f_0 and f_D/f_0 is negligible for probable values of r (e.g., 0.25–0.50). According to data given by Svedberg and Pedersen (*loc. cit.*) many of the homogeneous soluble proteins have frictional ratios of about 1.1 to 1.2, and it is possible that these proteins are solvated, substantially spherical molecules.

BOOK REVIEWS.

DIE ULTRAZENTRIFUGE, THEORIE, KONSTRUKTION UND ERGEBNISSE, von Prof. Dr. The. Svedberg und Dr. K. O. Pedersen. 436 pages, illustrations, tables, 16 × 24 cms. Dresden, Theodor Steinkopff, 1940. Price 26.25 R.M.

The ultracentrifuge as a tool in the study of high Molecular weight materials is a comparatively recent development. A book on the subject is therefore timely and should add considerably to development along these lines. The authors of this book are men of no little experience and their account here of their researches is quite well done.

The book is divided into four parts. Part one on the theory of sedimentation is devoted first to elementary theory in a centrifugal field, then to the velocity of sedimentation and sedimentation equilibrium. A mathematical analysis of the subjects is a feature here. Construction and operation of ultracentrifuges is the topic covered in part two. Specifications are given for high velocity centrifuges. Part three gives various methods of measurement and the evaluation of observations for experiments with monodisperse and polydisperse systems. Much data in the way of tables, curves and even photographs assist in this difficult but necessary section. The last part of the book on results obtained with Svedberg ultracentrifuges gives in good arrangement the researches in the laboratory with proteins and certain organo-colloids. Much of value of wide interest is revealed here.

The book is remarkable for its detailed coverage. It stands practically alone, only a reasonable knowledge being presupposed. The bibliography, name and subject index in the back add considerably to its value. The presentation stands as a monument to work done thus far and without doubt it is a large contribution to what will be accomplished.

R. H. OPPERMANN.

ELEMENTARY THEORY OF EQUATIONS, by William Vernon Lovitt. 237 pages, illustrations, 16 × 24 cms. New York, Prentice-Hall, Inc., 1939. Price $2.50.

There is scarcely a practicing engineer of any experience in the solution of design or analytical problems who does not recognize the importance and value of the application of mathematics. Equations are constantly presenting themselves for solution and methods for so doing are a welcome addition to the knowledge of engineering.

This book is a text of a grade suitable for students who have completed a one-semester course in Analytic Geometry and who have not had Calculus. The material deals with algebraic equations and with sets of linear equations including a few simple transcendental equations showing the generality and power of Newton's method of solution. It starts with a treatment on linear and quadratic equations, bringing out in the latter the occurance of complex numbers, and the reduction to a binomial equation. These threads are carried through to the method of finding the rational roots of an equation, then to the irrational roots.

Cubic and quartic equations are considered as well as bounds for and the separation of roots and the solution of simultaneous linear equations in "n" unknowns which are expressed symbolically in terms of determinants of order "n." The last chapter is devoted to ruler and compass constructions.

There is a wealth of material included in this book, making it flexible to suit a variety of classroom needs. The answers to the many exercises given at the end of each chapter appear in the back of the book, together with a subject index. This is a text that provides an excellent reference for engineers who wish to "brush up" on useful methods applicable to everyday work.

R. H. OPPERMANN.

STATISTICAL THERMODYNAMICS, by R. H. Fowler and E. A. Guggenheim. 693 pages, illustrations, tables, 19 × 27 cms. New York, The Macmillan Company, 1939. Price $9.50.

There is a gap in many fields between the higher theory and the more practical or applied theory, the bridging of which is very difficult to achieve without assistance of some sort. The accomplishment aside from having the advantage of bringing "down to earth" that which, by its nature, is necessarily vague, at least for some students, has the valuable attribute of clarification with attendant survival of interest.

In 1936 Dr. Fowler contributed to the literature the second edition of his book "Statistical Mechanics," well known to many. In it considerable sections were of purely astrophysical interest and many passages were devoted entirely to mathematical details of the proofs of the required theorems. On many occasions it deliberately avoids the use of ordinary thermodynamic methods. These are disadvantages to the student of chemistry or physics who desires a work of a more utilitarian nature. There is a need for the bridging of the gap to the more practical. The book at hand provides the assistance necessary to do this. It is a modified version of Statistical Mechanics in which the theory is developed somewhat parallel to Thermodynamics, so as to be complementary to a presentation of that subject. Mathematical details of proofs are taken for granted, and the applications confined to terrestrial physics and chemistry.

Those who are familiar with the 1936 book will find that in the first seven chapters of the book at hand there is little difference. These cover the subjects of the fundamental assumptions of statistical mechanics where theorems lay down the rules by which the equilibrium state of an assembly and its thermodynamic functions are to be calculated, permanent perfect gases, crystals, chemical equilibria and evaporation, Nernst's theorem, grand partition functions, their applications, and imperfect gases. The matter here has been brought more up-to-date and much of the calculation has been facilitated. Likewise, are the subjects following on liquids and solutions of non-electrolytes, solutions of electrolytes, surface layers, and elementary electron theory of metals. The next part of the book is devoted to chemical kinetics which the authors state is a subject outside of the province of the book but is included because the equilibrium theory, a survey of which is given, can be a useful tool if combined with certain assumptions concerning the mechanisms involved. In covering this, confinement is made almost entirely to gaseous reactions.

Under the topic of lattice imperfections, order-disorder in crystals, there is

made a study of the equilibrium concentrations of lattice imperfections of certain simple types, first in crystals of a single component, and secondly in crystals of a typical salt. This proceeds to imperfections which consist of the presence of extra atoms of one component and extended to consideration of the presence of foreign atoms in a lattice present either on lattice points or in interlattice positions. Then one is led to the general study of the solubility of foreign atoms in crystalline solids, and especially of the solubility of hydrogen in metals, particularly in palladium. In the closing part of this topic the degree of disorder due to atomic interchanges, as a function of temperature is studied.

The last chapter is devoted to electric and magnetic properties, where a somewhat condensed treatment is given, a balanced description of the general principles and results. In the back of the book there is a comprehensive subject index.

The work assumes considerable prerequisites. For those qualified to follow it, there is an abundance of interesting and valuable material presented.

R. H. OPPERMANN.

MR. TOMPKINS IN WONDERLAND, OR STORIES OF *c*, *G*, AND *h*. 91 pages, illustrations, 17 × 22 cms. New York, The Macmillan Company, 1940. Price $2.00.

Every one of us has set notions with regard to space, time and motion. These are obtained from infancy when the senses began to function. So set are they that they are taken for granted and often we are inclined to believe that our concept of the outside world is the only possible one. Those who have knowledge of modern scientific observation however, have ample reason to realize that a change in fundamental concepts is necessary when dealing with phenomena ordinarily inaccessible to our everyday observation, this change being necessarily restricted to such phenomena. If another world could be imagined with the same physical laws as our own, but with different numerical values for the physical constants determining the limits of applicability of the concepts, then even a savage would be acquainted with the principles of relativity and quantum theory.

This book contains a story, built up from the imagination, in which the hero is transported to such a world through a series of dreams, after attending lectures by the author on relativity of space and time, curved space and gravitation, and the quantum of action. The lectures are included in the latter part of the book. The worlds of course, seem fantastic, but the story has a special appeal to the scientifically minded reader from both the standpoint of the manner of presentation and the analysis of facts interpreted in a very real light.

R. H. OPPERMANN.

REFLEXION ET REFRACTION DES ONDES SEISMIQUES PROGRESSIVES, par L. Cagniard. 250 pages, illustrations, tables, 17 × 25 cms. Paris, Gauthier-Villars, 1939. Price 120 fr.

In this work the author reacts against the usual tendency of theoretical seismologists to consider an earthquake as a permanent harmonic phenomenon; whereas on the contrary it is a transitory occurrence—a motion gradually propagated in the midst of a medium which was originally in equilibrium.

Taking up by new methods a classic memoir of Lamb's which supplies indispensable generalizations, M. Cagniard discusses, with extensive use of mathe-

matics, the solution of one of the fundamental problems of seismology—that of the reflection-refraction of a spheric wave on the plane surface which separates the two media.

The phenomena of propagation, so much discussed today, on which was founded the refraction method of seismic prospecting, are definitively explained by the formation of waves with conical fronts at the time of reflection. In addition are studied the cinematic discontinuities, of which the various wave fronts may be the seat. These discontinuities become very complex when conical fronts are formed.

However, the essential part of the phenomenon consists neither in the propagation of wave-front surfaces nor in the cinematic discontinuities of which they are the seat. It lies rather in the subsequent phases of the disturbance which correspond to the "coda" of seismograms. This coda shows, at great distances from the epicenter, a characteristic aspect caused by the superimposing of complex phenomena designated by the author as pseudo-waves. The Rayleigh wave is a pseudo-wave whose structure is very different from that of the permanent harmonic phenomenon generally studied under that name in seismology. Beside the Rayleigh wave, there are many other pseudo-waves of varying types. Some are superficial like the Rayleigh wave and similarly characterized by an annular propagation. Others travel through the interior of the two media and not along their inter surface—and these are spheric or conical.

E. E.

PUBLICATIONS RECEIVED.

Elements of Electro-Magnetic Theory, by A. Wilmer Duff and Samuel J. Plimpton. 173 pages, illustrations, 15 × 22 cms. Philadelphia, The Blakiston Company. Price $2.75.

Elementary Photography, by Gilford G. Quarles. 350 pages, illustrations, plates, 16 × 24 cms. New York, McGraw-Hill Book Company, Inc., 1940. Price $3.00.

The Pinpoint Planetarium, by Armand Spitz. 110 pages, illustrations, plates, 26 × 21 cms. New York, Henry Holt and Company. Price $2.00.

Mechanics Applied to Vibrations and Balancing, by D. Laugharne Thornton. 529 pages, illustrations, 16 × 25 cms. New York, John Wiley & Sons, Inc., 1940. Price $7.50.

Science Front, 1939, by F. Sherwood Taylor. 310 pages, plates, illustrations, 13 × 19 cms. New York, The Macmillan Company. Price $2.50.

Radioactivite et Transmutation des Atomes, par Theodore Kahan. 224 pages, illustrations, 11 × 17 cms. Paris, Armand Colin, 1940. Price 17 fr.

Les Hautes Temperatures, par G. Ribaud. 173 pages, illustrations, 12 × 19 cms. Paris, Felix Alcan, 1939. Price 18 fr.

Portraits of Famous Philosophers Who Were Also Mathematicians, by Professor Cassius Jackson Keyser. 12 portraits, unpages, 26 × 35 cms. New York, Scripta Mathematica, 1939. Price $3.00.

National Advisory Committee for Aeronautics. Technical Notes: No. 755, Wind-Tunnel Investigation of an N. A. C. A. 23030 Airfoil with Various Arrange-

ments of Slotted Flaps, by I. G. Recant. 32 pages, illustrations. No. 756, The Effect of Piston-Head Shape, Cylinder-Head Shape, and Exhaust Restriction, on the Performance of a Piston-Ported Two-Stroke Cylinder, by A. R. Rogowski, C. L. Bouchard, and C. Fayette Taylor. 31 pages, illustrations. 2 pamphlets, 20 × 26 cms. Washington, Committee, 1940.

Bell Telephone System, Monographs: B-1200, The Physical Basis of Ferromagnetism, by R. M. Bozorth. 39 pages, illustrations. B-1201, A New Standard Volume Indicator and Reference Level, by H. A. Chinn, D. K. Gannett, and R. M. Morris. 44 pages, illustrations. B-1202, Contact Phenomena in Telephone Switching Circuits, by A. M. Curtis. 23 pages, illustrations. B-1203, Low Temperature Coefficient Quartz Crystals, by W. P. Mason. 20 pages, illustrations. B-1204, Effect of Quadrature Components in Single Sideband Transmission, by H. Nyquist and K. W. Pfleger. 11 pages, illustrations. B-1205, Auditory Patterns, by Harvey Fletcher. 46 pages, illustrations. B-1206, Statistical Measurements on Conversational Speech, by H. K. Dunn and S. D. White. 28 pages, illustrations. B-1207, Constants of Heavy-Water Rochelle Salt, by A. N. Holden and W. P. Mason. 7 pages, illustrations. B-1208, Lodgepole Pine Poles, by C. H. Amadon. 7 pages, illustrations. B-1209, Auditory Significance of the Term Hearing Loss, by John C. Steinberg and Mark B. Gardner. 19 pages, illustrations. B-1210, Molecular Rotation in the Crystals of Certain Benzene Derivatives, by Addison H. White, B. S. Biggs and S. O. Morgan. 22 pages, illustrations. B-1212, Oxidation of Vulcanized Rubber, by A. R. Kemp, J. H. Ingmanson and G. S. Mueller. 16 pages, illustrations. 12 pamphlets. 15 × 23 cms. New York, Bell Laboratories, 1939.